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A PRELIMINARY ACCOUNT OF THE GEOLOGY OF A PORTION OF THE LUPA GOLDFIELD.

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ABSTRACT.

The paper is based on work still in progress, which is the first detailed geological study that has been made in this new goldfield. The general geology is briefly described, together with the available factual data regarding the nature and origin of the lenticular gold quartz veins. These are abundant throughout the region, and their structure and simple mineralogy indicates that they are of the deep zone type. It is concluded that the mineralization is genetically related to a widespread invasion of the region by alaskite.

INTRODUCTION

THE Lupa Goldfield is situated in southwestern Tanganyika Territory, East Africa. It comprises about 800 square miles lying in the V made by the Rukwa Escarpment on the southwest and the Usangu Escarpment on the southeast, which belong to the "Great Rift Valley" systems of faults.[1] These two boundaries are natural and fixed, but the northern limits of the Goldfield are determined solely by the known occurrence of gold, and therefore may be ultimately extended by future prospecting.

The Mbeya Mountain mass [2] lies in the southern tip of the V, and at its southern base is the town of Mbeya, the gateway to

[1] Gregory, J. W.: The Rift Valleys and Geology of East Africa. Seeley, Service & Co., Ltd., London, 1921.

[2] Willis, B.: East African Plateaus and Rift Valleys, pp. 226–231. Carnegie Institution of Washington, 1936.

the Lupa Goldfield, served by a regular air line, and by a 404-mile dirt road from Dodoma on the railway. The road into the Lupa Goldfield climbs from Mbeya at 5500 feet, northward up the Mbeya Mountain mass to an elevation of over 8000 feet in the first fifteen miles. Descending the western slope it follows a divide with the Usangu Escarpment to the right, dropping a shear 3000 feet to the wide flats below, and to the left the accordant summits of the rolling hills of the heavily dissected eartern Lupa region. The plane formed by these accordant summits [3] slopes downward to the south and west. The road turns westward, following the divide, and the degree of dissection progressively decreases. Forty-seven miles from Mbeya, at an elevation of 5000 feet, is the town of Chunya, the geographical and business center of the Lupa Goldfield. The deeply dissected peneplane has now given way to the inselberg topography so characteristic of much of central Africa, that is, a flat plateau country dotted over with small "island mountain" masses of the erosion remnant type. About thirty miles west of Chunya the road skirts along the southern base of the Ilunga Range, the largest of the local inselberg masses, for a distance of about twenty miles. The Goldfield extends another fifteen miles west to Lake Rukwa.

The portion of the Lupa Goldfield under consideration in this paper is an area of less than one hundred square miles lying south of the Ilunga Range. Within it are three major prospects to which reference will be made; the Saza Mine, the Luika Mine, and the Razorback. Over ten thousand feet of development has been done on these properties, mostly at the Saza Mine, which is by far the largest undertaking on the Lupa Goldfield.

This part of Africa is in the southern savannah belt, and has a typically semi-arid climate. The entire annual rainfall of 35 inches falls during the rainy season from December to May, and is of torrential character.

[3] Grantham, D. R.: Lupa goldfield. Tanganyika Geol. Surv., Bull. 3, Dar es Salaam, 1932.

GEOMORPHOLOGY.

The area under consideration lies in general between the 3300 foot contour, which follows along the top of the 300 foot Rukwa Escarpment, and the 4000 foot contour which approximately marks the base of the Ilunga Range. The summits of the rounded mountains of the Ilunga attain nearly 6000 feet, but the area studied is a gently rolling piedmont slope.

It is drained by numerous intermittent streams that flow in a SSW direction from the Ilunga Range to the Rukwa Escarpment over which they plunge in waterfalls. The streams are intricately adjusted to lithology, and although faults are doubtless numerous in these pre-Cambrian rocks, none are apparent in the stream pattern. The stream control appears to be lithologic rather than structural.

The landforms and the adjustment of the streams indicate that the country had attained the late mature stage in the erosion cycle. Subsequent uplift or tilt has rejuvenated the streams, causing them to incize themselves with renewed vigor into their mature valley bottoms. The present load of the streams, therefore, is in part newly eroded rock and in part re-mobilized alluvium that had been previously spread over the country by the lateral swinging of the streams. The amount of soil in situ is smaller than might be expected, and the amount of old alluvium is correspondingly larger. Much of the gold has come from these high level alluvial deposits. The whole picture becomes clearer if one bears in mind that the country is composed almost entirely of pre-Cambrian abyssal igneous rocks, so that the erosion surface must have been let down through a distance of several hundred or, more probably, several thousand feet.

The simple picture of a mature region that has undergone rejuvenation, though correct, is doubtless incomplete; for the geomorphic history of an ancient terrain like this one, that has been jostled about in the incomparable Rift Valley faulting, must ipso facto be complex.

HISTORY.

The existence of gold in this region was known, but disregarded, during the period of German sovereignty. In 1922 gold was discovered in the Lupa River, and during the following year nine diggers worked the alluvium. But the region was inaccessible and unexplored; there was no indigenous native population for labor, due to the scarcity of water, and to native superstitions regarding the place. These factors inhibited the growth of the field, but gradually the diggers penetrated the country further and further westward, and the white population of the field reached several hundreds. Digging could be carried on only during the rainy half of the year, but about 1934 an Australian type of motor driven dry blower was introduced, which permitted work during the dry half of the year also and resulted in a further increase in the number of diggers and a marked increase in the production of gold. The history of this field is probably unique among the gold rushes of the world in that the rowdy element has never existed. The diggers are for the most part married men with their families, living quiet, neighborly lives.

PETROGRAPHY AND PETROLOGY.

Detailed petrographic work, which it is hoped will throw much light on the many problems of these ancient and complex igneous rocks, remains to be done. But tentative descriptions of the rocks may be offered on the basis of the megascopic field examinations and the small amount of microscopic work done to date.

All the rocks of the region are igneous and, except for a few dike rocks, they are all abyssal types. In briefest summary, the region appears to have been invaded by at least five successive batholithic intrusions.

As a result of the few weeks he was able to devote to the area, Grantham [3] found that it consisted essentially of a batholith of Saza granite in the southwestern part, a batholith of Ilunga granite forming the Ilunga Range in the northern part, and a zone of mixed gneiss, microcline granite, appinite, and other

rocks between. The obvious problem that awaited more detailed study was this zone of complex rocks lying between the two granite batholiths.

Quartz-Sericite Schist.—There are two zones of light tan colored, highly friable, quartz-sericite schist, each of which is represented by a series of detached masses that tend to form hills. The foliation stands nearly vertical, but the strikes are not uniform from one mass to another, which suggests that they may be engulfed blocks. On the other hand their occurrence in two crudely linear and parallel, but widely separately zones, favors their interpretation as roof pendants. Because this rock exhibits the highest degree of dynamic metamorphism in the region it is believed to be the oldest rock present.

Metadiorite.—Irregular, small masses of metadiorite up to half a square mile in area occur abundantly as remnants, possibly roof pendants, of what is believed to have been an almost continuous batholithic mass. These remnants are found enclosed in all the rocks except the quartz-sericite schist, and are therefore the second oldest in age. The metadiorite is represented by a wide variety of rock types due to the several kinds and degrees of metamorphism it has suffered in different places. No sharp line can be drawn between these types, for they represent a continuous gradational series. Essentially, a dioritic rock containing intermediate plagioclase was changed by autometamorphic processes to a rock composed of albite ($Ab_{94}An_6$), hornblende, and quartz. This was followed, probably at a much later date, by widespread propyllitic chloritization of the hornblende and the formation of sericite, calcite, zoisite, epidote, and pyrite. At a later time the rock was subjected locally to dynamic metamorphism resulting in shear zones within which it is now a chlorite-sericite-quartz-calcite-pyrite schist with pronounced foliation. These zones generally have a steep dip, and are important as loci of vein deposition.

The Diorite-Hornblendite Suite.—Several masses of a hornblende rich rock, which tends to form hills, occur in the eastern and western portions of the area. This rock exhibits a variety

of textures and compositions. It ranges from a rock composed entirely of greenish-black hornblende, in crystals averaging about 8 mm., through every quantitative gradation to a rock composed of not more than 20 per cent hornblende and 80 per cent plagioclase. These end members are uncommon, and for the most part the rock has a color index between 50 and 70. The more basic varieties are the most resistant to erosion. Texturally the rock shows a gradation of types from an equigranular mesocrate with grains averaging about 2 mm., to a coarse rock glittering with large oikocrystic hornblendes up to about 5 cm. in size. The origin and exact relationships of the rocks of this suite are not known. Not uncommonly these rocks are associated with the metadiorite, and in one place a gradation from metadiorite to hornblendite was observed in a distance of four feet. Grantham [3] believes that they were derived by remobilization of metadiorite by the later Saza granite, but this explanation is not entirely satisfactory in the light of the newly discovered facts. All that can be said of this rock at the present time is that its areal distribution has been mapped.

Metagabbro.—Another intermediate rock, which may or may not be related to the metadiorite, occurs abundantly in the eastern part of the area as attenuated, hill-forming outcrops with a northwesterly trend. It resembles an altered dolerite, and was distinguished in field mapping from the other intermediate rocks because it possessed a distinctive aspect that was invariable, a marked regional distribution and trend, and an outstanding toughness. Its age relations are not fully established but it is older than the granitic rocks.

Mawoga Granite.—In the study of this rock the problem of the zone of mixed rocks is met full face. In mapping the east central portion of the area numerous puzzling granites were encountered. The Microcline Granite of Grantham's classification was a clearly defined type, but areally less abundant than a host of other acidic rocks of doubtful category. As the field work progressed it became more and more apparent, and finally convincing, that all these granitic varieties fitted into several

interrelated gradational series, which included Grantham's Microcline Granite as one member of the group. This field conclusion must, of course, stand up against a searching microscopic check, and is here presented as nothing more than a working hypothesis. The term Mawoga Granite is suggested because the rocks of this suite are excellently shown in the valley of the Mawoga River and in the vicinity of the town of Mawoga. Furthermore, the term avoids any specific reference to composition, whereas Grantham's term, Microcline Granite, would be an anachronism if applied to many of the members of the suite other than the specific type to which he originally applied it. As a working classification seven major types have been set up with twenty-three subdivisions. It would be premature to describe them, but it may be said that sixty specimens can be arranged in a pattern of multiple cross connecting chains in which each chain is a gradational series. The end members are distinct types that bear little or no resemblance to one another. These include both melanocratic and leucocratic members, several varieties that are albitized, a tronjhemite-epidosite series, and members displaying several types of structure, mineralogy, and color. In summary it may be said that whereas Grantham [3] concluded that there was Microcline Granite (his G2) and an abundance of mixed Gneiss (including his G1), I have concluded tentatively that all these rocks are related and belong in one classification under the one term Mawoga Granite. The rocks of this suite are younger than the rocks already described and older than all the other granitic rocks.

Saza Granodiorite.—Grantham's Saza Granite constitutes the batholithic mass in the southwest portion of the area. The ratio of plagioclase to potassium feldspar is approximately 3½ to 1, and it therefore seems more fitting to re-name the rock Saza Granodiorite. It is a distinctive, coarse grained rock, normally consisting of large, white, nearly idiomorphic plagioclase crystals ($Ab_{77}An_{23}$), and coarse green hornblende, with some biotite and chlorite, which may be the dominant ferro-magnesians locally, together with interstitial quartz and microcline. The accessories include magnetite, apatite and conspicuous sphene. Rounded

xenoliths of metadiorite, and probably other rocks are locally abundant. To their assimilation Grantham attributes the hornblende content of the granite. Along part of the periphery of the mass the rock is mottled pink and green, with large pink phenocrysts of feldspar ($Ab_{68}An_{32}$) surrounded by a mixture of less coarse, greenish feldspar, hornblende, chlorite, and some epidote. Grantham attributes this type to assimilation also. But much remains to be found out by detailed microscopic work about the problem of assimilation vs. differentiation in the Lupa rocks.

The Ilunga Granite.—The Ilunga Range lies largely outside the area under consideration, but the rocks of which it is composed are important members of the regional suite. The Range consists not only of Ilunga granite, but also of important amounts of associated, and apparently consanguineous, granophyres and felsites. The granite is a medium-coarse grained, equigranular leucocrate of grey to pink color, composed essentially of microcline, oligoclase, quartz, and a very small amount of biotite, with accessory magnetite, apatite, and zircon. Bromoform separations reveal the presence of fluorite, and show the great predominance of zircon over the other accessories. The granophyres and felsites are grey, yellowish, or pinkish aphanites composed largely of micrographically intergrown quartz and feldspar. Grantham [3] has pointed out that many of these are silicified or granitized effusives. The Ilunga Range therefore may be an example of a granitic batholith that has stoped its way up into its own effusives, and on the other hand it may be a case of deroofing; but such idle speculations are useless except to point out the interesting problems offered by these rocks.

Both the Saza Granodiorite and the Ilunga Granite are clearly younger than the Mawoga Granite, but their mutual age relationship is still in doubt.

Felsites.—Small quantities of white, yellow, pink, or red hololeucocratic aphanites occur in the east central part of the area. These have been grouped together simply as felsites. They are older than the alaskite and younger dolerites described below.

Alaskite.—Throughout the area alaskite is found forming a

most complex configuration, ramifying, and fingering out all over the map, and injecting all the rocks except the young dolerites. It appears to have been emplaced in part by metasomatic processes, and in part by injection as dikes and larger masses. The situation may perhaps be best depicted by saying that the country has been squirted full and soaked through with alaskite. It is a strawberry ice-cream pink rock with medium grain size and an equigranular allotriomorphic texture, composed of quartz, albite ($Ab_{94}An_6$) microcline, orthoclase, and generally a small amount of muscovite that seems to be largely deuteric. Accessory magnetite is present, and a very small amount of apatite, rare zircon, and a trace of epidote. Locally the rock is a biotite-alaskite, and near contacts with hornblendic rocks that have been metasomatically attacked by it, an anomolous hornblende-alaskite has been observed. Crystallization appears to have taken place in the normal Rosenbusch order, although the textural relations suggest that the microcline and quartz, both of which encroached upon the albite, were approximately contemporaneous, and that the orthoclase may be in part later than some of the quartz.

Mr. Frank Oates, Petrologist and Chemist of the Tanganyika Geological Survey, offered to determine SiO_2 in this rock, and then kindly returned the excellent, full analysis and calculation of the Norm given below, for which I wish to thank him and the Survey.

Dolerites.—Dolerite dikes are abundant, particularly in a swarm that strikes southeast-northwest across the area. They cut all the other rocks and are referred to as the young dolerites. Dolerites of other strike are present but less common. Older dolerites, possibly of several ages, occur as xenoliths in the granitic rocks, and it is hoped that a detailed study of these may throw some additional light on the age relations of the rocks in general. In addition to normal dolerite, olivine bearing and quartz bearing varieties have been noted.[3]

Miscellaneous Rocks.—A number of additional rock types were encountered in the field in minor quantities. Many of these are doubtless variants of the rocks noted above, but a few are

	I	II	III
SiO_2	76.64	75.01	76.47
TiO_2	.02	.06	.07
Al_2O_3	13.55	13.88	13.03
Fe_2O_3	.27	.74	1.04
FeO	.18		
MgO	.08	.09	.06
CaO	.68	1.00	.45
Na_2O	3.80	3.52	3.53
K_2O	5.27	4.89	4.81
H_2O+	.12	.26	.52
H_2O-	.02	.11	
P_2O_5	.03	tr.	.01
MnO	.00?	tr.	.01
Cl	.04	n.d.	
S	*	n.d.	
Cr_2O_3	*	n.d.	
BaO	†	.10	
SrO	*	tr.	
	100.70	99.66	
Less o for Cl	.2		
	100.68		

	%
Quartz	32.9
Orthoclase	31.1
Albite	32.0
Anorthite	3.3
Corundum	.4
Hypersthene	.3
Magnetite	.2
Ilmenite	tr.
Apatite	tr.
	100.2

I. Alaskite from Lupa Goldfield, Frank Oates analyst.

II. Alaskite from Skwentua River, Alaska, H. N. Stokes analyst, ref. J. E. Spurr, Amer. Geol., 25: 231, 1900.

III. Daly's average. Daly, R. A., Igneous Rocks and the Depths of the Earth, p. 26, McGraw-Hill, 1933.

* Not detected.

† Trace, not determined.

probably distinct intrusions. Among them are several dike rocks, including a lamprophyre, a tonjhemite that may be related to the Saza Granodiorite, and the Luika quartz-monzonite. The latter, which occurs in the northwestern part of the area and may possibly be identical with Skerl's "younger, light grey, fine grained, biotite granite,"[4] is of local importance as the wall rock of the Luika vein.

These brief notes should suffice to indicate the complexity of the rocks and the abundance of problems to be solved by detailed

[4] Skerl, A. C. and Oates, F.: The Geology of the North Ilunga Area, Tanganyika. Tanganyika Geol. Div. Short Paper 18, Dar es Salaam, 1938.

petrographic study. Five successive major intrusions, the metadiorite, the Mawoga Granite, the Saza Granodiorite, the Ilunga Granite, and the alaskite, have occurred at the same place, each partially destroying those that preceded it. Widespread regional albitization has occurred, possibly at least twice. Local intense epidotization has occurred at many points. Lastly, these rocks offer abundant evidence bearing on the assimilation versus differentiation controversy.

Structural Geology.

Evidence of the structural history of the region is lacking because of the profuse alluvial regolith and the massive character of the rocks. Nor does the stream pattern, adjusted as it is to lithology, reveal any noteworthy structural features, except perhaps in the Ilunga Range, where two sets of fractures, with NW–SE and NE–SW directions, have controlled the formation of the valleys.

Two periods of diastrophism are indicated by the schistosity of the quartz-sericite schist and the shear zones in the metadiorite. The gneissic structures met locally in the granitic rocks are due to magmatic flow because the consanguineous pegmatites that cut across the gneissic structures are undeformed.

Faults are not common in the mine openings, which provide the only satisfactory places in which to search for them, although small slips are abundant, which are all, invariably, of the tensional type. Tension is also indicated by the pattern of the dolerite dike swarm, the alaskite, and the felsites. The felsites commonly appear as small dikes that filled fractures under the influence of tensional stresses, and tension appears to be necessary in order to explain the emplacement of part of the alaskite. The Rift Valley faulting is generally also attributed to tension, but as a mere marginal feature of the area it hardly need be considered here.

In summary, then, the region appears to have been under little stress other than occasional tension, and two minor periods of diastrophism, throughout its long history.

Economic Geology.

The region contains the following mineral resources. Gold occurs in quartz veins and in eluvial and alluvial deposits. Beds of coal at Galula, about twenty-five miles south of the Lupa Goldfield, have not been developed, but are a potential source of power for the community. Limestone occurs as small surficial deposits of terrestrial origin, in amounts sufficient for cyanide-plant lime. Salt, which is an essential item of food issue for the native laborers, occurs within a few miles in the salt pans of the interior drainages caused by the Rift Valley faulting. Molybdenite has been noted at Luika as a subsidiary mineral that may prove salvagable as a bi-product of the gold mining. The silver content of the ore is probably too low to warrant its recovery. Bat guano, for fertilizer, is mined near Mbeya, and adequate quantities of sand and clay for building purposes occur throughout the region. Only the gold quartz vein deposits are to be considered in the present paper.

The Gold Quartz Vein Deposits.

General Character.—Auriferous quartz veins are widely distributed and surprisingly abundant in the region. They dot the map profusely, and are found in all the rocks except the young dolerites. They show all possible directions of strike, and no pattern can be seen in the heterogeneity of their distribution and orientation. In form they are typically lenticular. They range in size from minute stringers to the large Razorback vein which is about two miles long and of the order of fifty feet wide. A large number of them, however, are tens or a few hundreds of feet in length, and from one to five feet wide. The angles of dip are generally steep, but little is known of their vertical extent at the present stage of development. Diamond drilling has been done only at Saza, and here the ore has been traced to a depth of about seven hundred feet.

Mineralogy and Structure.—The veins are of the massive type characteristic of the deep zone deposits, and show no crustification or similar shallow zone features. They are composed

almost entirely of quartz, and the other minerals exist as little more than traces. These include chlorite, sericite, carbonates, tourmaline, pyrite, chalcopyrite, galena, molybdenite, and gold. But the combination and distribution of these minerals differs from vein to vein, and within the individual veins.

A number of varieties of quartz are present, including white bull-quartz, glassy quartz, porcelain-like quartz, smoky quartz, blue quartz, and red cryptocrystalline silica. Many of the veins are the white bull-quartz type often referred to as "hungry," and devoid of mineralization. Of the others, the Luika vein offers a typical example. Here the quartz ranges from clear milk white to dark blue, and from nearly transparent to barely translucent. The blue color is most commonly of an intermediate shade. Color transitions do not always occur between the white and the blue quartz, for in places the two extreme types are contiguous, although in many such occurrences a fracture plane, commonly with a little gouge, separates the two. In places the white and the blue are intermingled giving rise to a very irregular mottling, or to a bacon-like streaked pattern.

The longitudinal streaked pattern of the veins may also be due to other features. Multiple fractures, parallelling the walls, are abundant in some, and are commonly spaced at about 1 cm. intervals, although in places as many as fifteen to the centimeter may be observed megascopically. The resulting quartz does not, however, have a schistose aspect, and as there is little or no comminuted material in the fractures, slipping has not occurred along them. In many of the veins, notably at Saza, there are multiple, film-like layers of chlorite, approximately parallelling the vein walls, and in places contorted into complicated little folds. A similar banded appearance may be caused by tourmaline or sulphide streaks. Such mineral streaks are generally no more than a few millimeters wide, and are of various lengths up to several meters. They too occupy zones of planar form roughly parallelling the vein walls, but differ from the chlorite films in that they are not so obviously associated with fracture planes, and indeed are commonly zones with nebulous boundaries.

Tourmaline, when present, is generally abundant, and conspicuous because of its black color, but it is entirely lacking from most of the veins in the region. It occurs as concentrations of needle-like crystals, not only in streaks but also as irregular shaped masses, some of which have solid tourmaline cores and edges made indefinite by the intermingling of the tourmaline needles and quartz. The distinctive light brown to dark purple pleochroism of the Lupa tourmaline, and its occurrence in veins of good gold value, would make it a useful mineral in tracing the movements of eluvium by the heavy mineral separation method.

The sulphides too are not restricted to streaked zones, but occur also in masses of irregular shape. Pyrite is by far the commonest, and occurs in particles of a wide range of size, from dust-like dispersions to cubes more than a centimeter on a side, and rarely in larger masses. Quantitative determinations have shown that its total bulk is less than one per cent of the vein material. Associated with it is chalcopyrite in distinctly subordinate amounts, although in a few veins in the Lupa it is conspicuous. Galena is rare, but it may be found in small, local concentrations in many of the veins. It is a sign of excellent local values, but since it occurs generally in such small amounts, rarely exceeding a few handfuls, its presence is of little value except to the small worker who can use such materials to sweeten a little arrastra. Molybdenite has been observed only at Luika. Here the vein is composed of broken fragments of first generation quartz with pronounced strain extinction, cemented together by a fine-grained second generation quartz with only slight strain extinction. The molybdenite occurs as minute disseminated, hexagonal crystals restricted to these interstitial areas of second generation quartz.

Much of the gold is below visible size, but visible particles are not uncommon. Nuggets over one hundred ounces in weight have been found in the alluvial diggings, and occasionally so-called "jewel shops" are encountered in the veins. A recent find is reported as "tons milled: ¼; gold recovered 332.97 oz." [5]

[5] Personal correspondence.

Carbonates are locally abundant, although they are entirely absent from most of the veins. They are from white to pink in color, and qualitative tests show the presence of calcium, magnesium, iron, and manganese. A study of the quantitative variations of these four components with variations of depth [6] and ore tenor should be made. The carbonates generally occur as late fillings in small cross fractures, but their exact genetic relationships are not clear.

Sericite is ubiquitous in small quantities, but is particularly important as a constituent of the altered wall rocks.

Microscopic work may reveal other minerals in these ores. Three chemical analyses have been made of the ore from Saza, Luika, and the Razorback. Each was run on a composite sample made from a large number of assay pulps, but they are not very satisfactory. Each gives "Te trace less than .005 per cent," suggesting the possible presence of gold tellurides. But Bi, As, Sb, Ni, Co, and Pb were reported as "not found" although galena has been observed megascopically in all three of these deposits. Therefore, the mineralogy, as suggested by the analyses, may or may not be more complex.

In addition to the longitudinal pattern already mentioned, a cross pattern is exhibited by some of the veins, but in all cases this cross pattern is due to late fracturing. Some of the fractures appear to have formed near the end of the ore-forming process and are filled with quartz. Others that may belong to the same, or a later period, are filled with carbonates, and a few are filled with bright red cryptocrystalline silica. Fractures that appear to belong to a much later period of stress are abundant, but contain no mineral filling.

Inclusions are not common in the veins. Angular or lenticular blocks of wall rock are encountered in places, and these are in some cases located near, and are presumably related to, bifurcation points.

The veins seem to be nearly ideally lenticular with horizontal and vertical dimensions approximately a hundred times their

[6] Charlewood, G. H.: The nature and occurrence of carbonates in veins. ECON. GEOL., 30: 502–517, 1935.

thickness. Fatter lenses are uncommon, and generally belong to the white bull-quartz variety. As might be expected, most of the lenses have tapering ends, but this is not always true, for some with very blunt rounded ends have been encountered in mine development. These may be in a linear series, like boats bow to stern, and the rounded sterns truncate the structure of the enclosing rocks.

Numerous other cases have been observed underground of a lack of conformity between the veins and the structure of the enclosing rock, and indicate that the veins were emplaced, at least in part, metasomatically.

The chaotic strikes on the surface have been mentioned, and their failure to show any discernable pattern. Some observers in the Lupa have been lead to see patterns that seemed obvious enough when a few veins were plotted, but which disappeared when the fuller evidence of a larger number of veins was available. Similarly, observations in the vertical direction are limited to two levels and a few raises, winzes, and shafts in the Saza and Luika mines, and to small shafts and single levels in a few other mines, so that any postulates based on the meagre data available may lead to incorrect conclusions, but the observed data may be mentioned tentatively.

The vertical pattern is more complex than was at first supposed, for in many cases veins encountered underground and presumed to be the downward extension of veins observed in approximately the right corresponding position on the surface, have been found to be merely new lenses with an en echelon relation to the veins above. This has introduced a disappointing error in some early ore calculations, that has been disclosed only after vertical development. In only two places in the Saza Mine, and probably no where else in the Lupa Goldfield, are there sufficient openings to yield useful data, and in both of these places there is a suggestion of a greatly attenuated reticulate pattern of the *en echelon* veins. Whether this is the general case remains for future mining to show.

Faulting has not as yet presented any difficulty to the miner.

Small slips are numerous, but all those so far observed have been tensional strike slips involving a displacement of a few feet at the most. Veins that have tapered off against such slips in development headings are generally found in a round or two by following the slip, although in some cases nothing more than a series of small quartz blebs is found indicating the termination of the lens. Elsewhere on the field, faults have been postulated to explain the distribution of veins, but it is doubtful if any of these faults have actually been observed.

Additional Features Regarding Gold.—Little is known about the tenor of the ore. The officials of the Tanganyika Department of Lands and Mines have tried persistantly, but with little success, to persuade the local mine operators to employ regular methods of sampling and assaying. In the larger mines, where proper methods have been used, the ore grade for various shoots averages between four and fourteen pennyweights per short ton. In places, values are fairly consistent over lengths of a few hundred feet, but for the field as a whole, the scanty evidence indicates that values are erratic.

A feature of the mineralogy that remains to be explained is the fineness of the gold. Ninety-four partings from a number of veins, but principally from Saza, show a range from 143 to 882 and average 499. Furthermore, the yield from several of the Lupa Goldfield mills has been disappointingly high in silver. This condition is contrary to the expectable fineness of the gold from deposits with the structure and mineralogy that these process.[7] Several possibilities may be called to mind; (1) the presence of silver minerals to be disclosed by mineralographic work; (2) refining[8] by the processes of groundwater solutions and secondary enrichment; and (3) the possibility of more than one period and type of mineralization. That microscopic study of polished sections will reveal additional minerals is to be expected. That none of the fineness data so far available has come

[7] Lindgren, W.: Mineral Deposits, pp. 262, 616, 628, 750. McGraw-Hill, New York, 1928.

[8] Knopf, A.: The fineness of gold in the Fairbanks district, Alaska. ECON. GEOL., 8: 800–802, 1913.

from below the zone of possible oxidation is a fact. And the possibility of more than one period of mineralization is plausible in the light of several facts that require much more detailed study. A graphic plot of the variation of fineness with richness shows no interdependence between the two.

The formulation of tentative rules for the correlation of gold values and mineralogy may be attempted, but evidence is scattered and fragmentary, and applies rather to individual veins than to the region as a whole. By customary prejudice the white bull-quartz veins are valueless; but one particularly uninviting vein yielded a specimen with a gold nugget the size of a pea. However, although such veins may carry rich gold in spots, the spots are evidently too few and far between to be mined at a profit. Dark colored quartz, on the other hand, particularly the blue variety, is an indication of good values at Saza and Luika. Underground mapping and microscopic examination of the ore at Luika has disclosed a possible explanation. In accordance with the elementary principles of ore deposition with falling temperature, the sulphides and gold are restricted to the fine-grained second generation quartz. Although the metallic minerals may themselves contribute to the dark color of the quartz, it is possible that loss of light by multiple internal reflection may also contribute to the dark appearance. The blue quartz and the white quartz were designated by separate colors on an underground map, and when an assay map was superposed it became immediately apparent that payable ore occurs where the quartz is blue, and only where the quartz is blue.

Most of the veins are massive quartz showing little internal structure, but the veins that present the greatest economic promise are generally those that are banded quartz with chlorite films, and tourmaline or sulphides. The presence of such bands, particularly of chlorite, generally portends good gold values, but the gold is probably not so much associated with the chlorite itself, as with the sulphides that are associated with the chlorite.

Correlation of gold values with the pyrite shows two clear relationships. A particularly rich specimen of pyritized wall

rock, which contained no visible gold, assayed as a whole over 200 dwts., but an assay of the pyrite alone showed more than 1300 dwts. Mackay's [9] conclusion that "at . . . Saza . . . the sulphides definitely do not carry gold," does not seem to be supported by the observed facts. Of further significance is the correlation between gold values and the size of the pyrite particles. Portions of the veins containing coarse pyrite crystals have been found to contain very little gold, whereas the portions containing finely disseminated pyrite are of good value. Several obvious explanations suggest themselves, but for the present it may simply be said that the relationship seems to be sufficiently constant to warrant the local rule and its converse: the finer the pyrite the better the gold.

Observations at Luika and Saza indicate that the nature of the wall rock has had no effect on the grade of primary ore deposited. Robert A. Mackay [10] after a detailed study of far more extensive data collected from all parts of the Lupa Goldfield has reached the same conclusion. Although the grade of the ore has not been effected, and although the quartz veins occur in all of the rocks of the region with the exception of the young dolerites, it is evident that the metadiorite was a particularly favorable host rock because of the shear zones within it that offered favorable channelways for the ore-bearing solutions. This is not attributable to the age of the shearing stress, for the shearing occurred after the formation of rocks younger than the metadiorite; but is to be attributed to the abundance, in the metadiorite, of the constituents necessary for the formation of the platy mineral chlorite.

At the present stage of development little data exists on the configuration of the ore shoots, and the vertical variations in the character of the ore. The ore shoots observed in drives are rarely less than one-hundred feet in length, and shoots more than six-hundred feet long have been developed at Saza.

[9] Mackay, R. A.: Outline of Recent Developments on Lupa Gold Fields, Tanganyika Territory. Jour. of the Chem. Met. and Mining Soc. of South Africa, 37: 98–108, 1936.

[10] Personal communication.

The usual evidence of oxidation is present in the outcrops of the veins, but not abundantly, such as iron oxide stains, pyrite boxwork, dendritic manganese oxides, and traces of malachite. These persist, but with steady diminution, to a depth of about one-hundred feet, beyond which they are entirely lacking. The sheared character of the wall rocks of some of the veins, and the abundant fractures in the quartz, provide the permeable passage-ways necessary for the movement of ground water solutions to effect oxidation and secondary enrichment. The ground water of the region contains about one and one-half parts per million of chlorides, about one-thousand parts per million of carbonates, and has a hardness of about five-hundred. Therefore, since chlorine, sulphides, and manganese oxide are present, although in very small amounts, and the rocks have adequate permeability, it is inevitable that some solution and migration of the gold has occurred together with possible secondary enrichment. Shaft assays indicate a rise in values to a depth of about twenty-five to forty feet below the surface beyond which there is a diminution of values to a figure slightly in excess of the surface tenor. That the surface zone overlying the enriched portion is of nearly the same tenor as the primary ore below the zone of oxidation suggests that removal of gold from the outcrops, both by erosion and solution, has been nearly compensated by residual enrichment within the outcrops.

The total amount of secondary enrichment is very small, and although small amounts of attractive ore are valuable to the small worker, the factor of secondary enrichment need not trouble the mining engineer in evaluating the deposits. The fact he must bear in mind is that the gold values above about one-hundred feet of depth have been subjected to migration, and obviously assays determined within the zone of this activity cannot be reliable. The degree to which the process has moved the gold about is unimportant because it merely effects the degree of unreliability of the assays, and no reliance can be accorded an unreliable assay regardless of the degree of doubt.

Milling at the present time with small stamp and ball mills,

grinding to about forty mesh, followed by amalgam plates and blankets, is moderately successful, but of course gives only partial recovery. Less success is to be anticipated when the oxidized ore is exhausted and treatment of the primary ore is attempted, as detailed milling tests on Lupa ore indicate that an "all-sliming" process involving fine grinding and long agitation in cyanide, is advisable.

Wall Rock Alteration.—Within the area, mine openings to date afford the opportunity of observing the alteration of only two kinds of wall rocks, the metadiorite at Saza, and the metadiorite and quartz-monzonite at Luika.

At Saza the veins occur in a shear zone that is vastly wider than the veins themselves. The wall rock is sheared metadiorite composed of chlorite, sericite, calcite, pyrite, and quartz. Slight mineralogical and color changes may be observed near the veins in some places, but generally the character of the sheared metadiorite next to the veins shows no megascopically perceptible difference from the sheared metadiorite many feet away. There is a complete gradation from the normal metadiorite to the sheared variety in places where no veins occur, and it can only be concluded that the vein forming processes have caused little or no wall rock alteration of the metadiorite at Saza.

At Luika the Adit Level follows the vein, and its accompanying parallel fault, about 1200 feet. The first 500 feet is in metadiorite, and here, as at Saza, little wall rock alteration can be detected. The remaining 700 feet is in quartz-monzonite, and throughout this portion the marked wall rock alteration is noteworthy. The contact between the two rocks has been the locus of complex igneous injection. Apophyses of the quartz-monzonite injected the metadiorite, then both rocks were injected by dikes of alaskite within the general confines of the metadiorite, and lastly all three were injected by a dolerite dike. The alaskite dikes are of paramount interest. They are about one to two feet thick and have half-inch chilled selvedges that would make creditable illustrations for a textbook. There can be little doubt of their injected character. They are composed entirely of quartz

and albite ($Ab_{94}An_6$) with a trace of deuteric muscovite. The albite shows a tendency toward hypidiomorphism but there has been interference during growth and slight, but definite, deformation. The quartz is clear and shows several degrees of strain, indicating deposition over a span of time during which the stress diminished, so that the first formed quartz was highly strained, and the last quartz was deposited after the stress had become ineffective. It is to be noted that this rock and the regional alaskite are identical. Small pegmatoid apophyses of the alaskite, both at Luika and elsewhere in the field, have been observed to end in pure quartz terminations.

The quartz-monzonite wall rock at Luika has suffered albitization and silicification. Close to the vein the rock is composed of albite ($Ab_{94}An_6$) and quartz with a little sericite and pyrite. The albite is generally bent, twisted, fractured, and microfaulted, and sections normal to Z show no twinning but have undulatory extinction. The quartz shows several degrees of strain, exactly as in the alaskite dikes. The sericite is restricted to the confines of the albite grains, generally in close association with the pyrite, and although universally present it is rarely abundant. The grain size is medium to fine and seriate, and the texture is complicated by the effects of metasomatism and dynamic deformation.

The history of the rock as interpreted from thin sections is: (1) metasomatic replacement of the quartz-monzonite by albite and quartz, (2) dynamic deformation by crushing with subordinate shearing, and (3) the metasomatic introduction of more quartz accompanied by pyrite with which was associated some sericitization affecting the albite. Evidently the movement and metasomatism continued over a finite span of time, with all the albite preceding the movement, and all the pyrite, together with some of the quartz, following the deformation, as indicated diagrammatically below:

The quartz grades, by the appearance of albite in increasing amounts, into the altered wall rock composed of albite and quartz, and this in turn grades within a few feet into the quartz-monzonite by decrease of albite and quartz and the gradual increase of the normal constituents of the country rock. Hence there is, in effect, a gradation from the vein quartz to quartz-monzonite through an intervening zone of wall rock alteration. The altered wall rock is as clearly metasomatic as any textbook example, yet this wall rock is apparently indistinguishable in thin section from the equally ideal, injected alaskite of the dikes. It may therefore be concluded that the alaskitic altered wall rock, the alaskite dikes, and the regional alaskite, are identical.

In the main cross-cut on the second level at Luika, at a point about sixty feet into the hanging-wall from the vein, is a fracture. On both sides of this fracture, which contains no quartz vein, the quartz-monzonite is altered to the typical quartz-albite-pyrite sericite wall rock for a distance of about two feet, and this alaskite assays about 4 dwts. of gold.

Origin of the Ore.—The age of the mineralization, and of all the rocks, except the young dolerites, has been assigned by the Tanganyika Geological Survey to the pre-Cambrian, or at least to pre-Bukoba time.[11]

Grantham [3] tentatively suggested that the veins were genetically related to the "Saza granite," but the evidence gathered during the present investigation compels the rejection of this hypothesis, and the formulation of a new concept of the origin of these veins.

A genetic relationship between the mineralization and the alaskite is indicated by the following points. (1) The close geographical association between the quartz veins and the alaskite, as observed in the field and shown on the new geological map of the area. (2) The regional alaskite is identical with the alaskite dikes in the Luika mine and the alaskite wall rock alteration along the Luika vein, which is genetically related to the vein itself.

[11] The Bukoba is "Pre-Devonian and probably Paleozoic." Teale, E. O.: Provisional Geological Map of Tanganyika with Explanatory Notes. Tanganyika Geol. Surv., Bull. 6, 1936.

(3) Small apophyses of alaskite may end in pure quartz terminations. (4) Metasomatic alaskite has been observed to carry significant gold values.

The necessity of fracturing of the early formed vein material to permit the entrance of the later, and presumably lower temperature, solutions is indicated by: (1) the lack of gold in veins that do not show this feature, such as the solid, structureless, white bull-quartz veins, and the veins containing only coarse pyrite and tourmaline, as in 6A at Saza; and (2) the presence of gold in the veins that do show this feature, such as those composed of blue quartz, or other fine-grained, second generation variety, together with chloritic films and fine-grained pyrite.

No mineralogical precipitant appears to have been necessary for the localization of gold deposition because: (1) auriferous veins occur in all the diverse rocks present, (2) the values do not preferentially follow the walls, and (3) the high grade material of the " jewel shops " may consist of gold and quartz alone. The spotty nature of the values is not attributable to the sporadic distribution of precipitants, but instead to the loci of available permiability at the time of entrance and movement of the mineralizating solutions.

The structural and mineralogical characters indicate that the veins were formed under the conditions of the upper hypothermal or lower mesothermal zones, but the possibility of telescoping or of two periods of mineralization must not be ignored. A considerable temperature variation during mineralization is suggested by the lack of mineralogical uniformity; the variety of quartz types, the inconstant grain size of the tourmaline and sulphides, the sporadic occurrence of carbonates, galena, molybdenite, and red cryptocrystalline silica, and the silver content of the gold. In the light of several facts, which have been discussed informally in the field, the possibility of more than one period of mineralization cannot be dismissed until the fuller evidence afforded by much more extensive mine development has been carefully studied in the field and laboratory.

The region was " squirted full and soaked through with

alaskite," which appears to have sought out and filled all available openings to such an extent that it was forced to continue its invasion by non-selective metasomatic replacement. Yet the quartz veins, which were a late comagmatic derivative of the alaskite, were able to follow on and still find channelways of entrance, for the loci of quartz vein deposition were determined by permeable channelways, such as the shear zones in the metadiorite and the fault at Luika. If such channelways had existed during the invasion of the alaskite they would have been filled by it, and the alaskite would not have been forced to seek entrance by metasomatism. It is therefore apparent that the alaskite invasion was accompanied in its later stages by earth movements that opened new channelways to permit the entrance of the quartz vein-forming solutions. Tension appears to have operated, but as indicated by the replacement structures observed underground, the openings were insufficient to permit the entire process to proceed by fracture filling, probably because of the depth at which the process was carried on as indicated by the mineralogy of the veins, so that much of it had to be accomplished by metasomatic replacement.

Conclusion.—The region is composed of complex, pre-Cambrian, igneous rocks in which abundant, characteristically deep zone, gold quartz veins occur, that were deposited metasomatically in fracture channelways by solutions that were genetically related to a widespread invasion of the region by alaskite.

BROOKLINE, MASS.,
January 18, 1939.

THE IRON ORES OF THE WICHITA MOUNTAINS, OKLAHOMA.[1]

C. A. MERRITT.

ABSTRACT.

The magnetite and hematite deposits of the Wichita Mountains, southwestern Oklahoma, have not been described except for a few brief references to the hematite ores. A summary of the geology of the area is presented herewith as well as a description of the deposits. The results of chemical and microscopic studies are included and also a brief discussion of the origin of the ores and their economic possibilities. The magnetite is titaniferous and is intimately associated with Pre-Cambrian anorthosites. The ores probably were formed by magmatic segregation from the anorthosite magma, and later were subjected to hydrothermal alteration. The hematite deposits are oölitic, containing bands of hematite alternating with chamosite in the spherules. This ore is found in the Reagan sandstone (upper Cambrian) and probably originated contemporaneously with the sediments. Some hematite, however, may have been formed later by the oxidation of part of the chamosite.

The average of six analyses shows 8.40 per cent titanium oxide in the magnetite ores, and consequently, at the present time, the deposits are not considered to have economic possibilities. The hematite ores have an iron content between 7 and 35 per cent Fe, which is too low for profitable mining. Some paint pigment has been made from the hematite and there is a possibility that the ore might be utilized for this purpose.

CONTENTS.

Introduction 269
General geology of the area 269
Description of the magnetite deposits 274
Chemical character of the magnetite ores 276
Microscopic character of the magnetite ores 277
Origin of the magnetite deposits 279
Economic possibilities of the magnetite deposits 279
Magnetite sands of the Wichita Mountains 280
Hematite deposits of the Wichita Mountains. 282

[1] Published by permission of the director of the Oklahoma Geological Survey.

INTRODUCTION.

DURING the last half of the nineteenth century a few prospectors visited the Wichita Mountains and after cursory examinations of the area reported that they had found valuable mineral deposits. In 1901 the lands of the Kiowa and Comanche reservations were opened by lottery for settlement. The settlers, spurred by the rumors of gold and other metals, initiated an intensive prospecting compaign in the area, which activity continued for several years. Every quartz vein, every type of igneous rock and many of the highly colored Permian sediments were tested by shallow pits, shafts, and trenches, and numerous assays were made. A few attempts were made to mine the ores and even machinery and plants were installed in some instances. No commercial deposits were developed but several interesting mineral occurrences were uncovered. Among them were the hematite and magnetite ores that form the subject of this study.

During this century there has been little exploratory work in the Wichita region and the iron ores have been neglected, although there have been a few attempts to develop the hematite deposits. No detailed studies of the ores have been made and the literature on the subject is confined to a few short references.

During the recent State Mineral Survey [2] these deposits were investigated and sampled. The results of these studies are presented in this preliminary report.

The author wishes to acknowledge the co-operation and assistance he has received from all of the members of the Oklahoma Geological Survey.

GENERAL GEOLOGY OF THE AREA.

The geology of the region has been described [3] and no attempt is made here to review it completely. However, a knowledge of

[2] W.P.A. Project 65–65–538, sponsored and directed by the Oklahoma Geological Survey, 1936–37.

[3] Hoffman, Malvin G.: Geology and petrology of the Wichita Mountains. Okla. Geol. Surv. Bull. 52, October, 1930. Taff, J. A.: Preliminary report on the geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma. Okla. Geol. Surv., Bull. 12, 1928. Taylor, C. H.: Granites of Oklahoma. Okla. Geol. Surv. Bull. 20, December, 1915.

some of the broader features is essential to an understanding of the iron ores and therefore a brief summary of the points pertinent to this study will be given.

The iron ores are located in Kiowa and Comanche counties of the Wichita Mountains, southwestern Oklahoma. These mountains form a physiographic unit consisting of mountains, hills and knobs extending from northwest of Fort Sill to beyond Granite, a distance of sixty-five miles. The width of the Wichitas is variable, being twenty-eight miles at the widest point and only a fraction of a mile at the northwest end. The mountains are not continuous but rather a series of peaks and hills of various sizes separated by low areas.

The hills of the region are composed mainly of Pre-Cambrian granophyres and gabbro-anorthosites. The flats are underlain by basic igneous rocks and also by Permian " red bed " sediments. On the outskirts of the region some of the hills are formed of early Paleozoic sediments.

The igneous rocks in all probability, are one continuous mass below the surface, and underlie the Permian sediments, being exposed only where they are sufficiently high to protrude above the sedimentary mantle. This view is substantiated by the encountering of igneous rocks below the Permian in well cuttings from various places in this region.

The igneous rocks are Pre-Reagan (Upper Cambrian) in age and generally are considered to be Proterozoic, though this is not proven. The age relationships of the Pre-Cambrian rocks as given by Hoffman [4] follow: Quanah granophyre and dike rocks (youngest); Lugert granophyre; Carlton granophyre; Davidson granophyre; Saddle Mountain granophyre; Gabbro-anorthosite; Meers quartzite (oldest).

Meers Quartzite.—The Meers quartzite is the oldest rock in the region. It is exposed in three small outcrops, two of which are in the vicinity of Meers as indicated on the map. Two of the exposures have been intruded by gabbro and the third by granophyre, all three showing some evidence of contact metamorphism.

[4] *Op. cit.*, pp. 39–44.

The quartz grains are subangular to rounded and vary in size from 0.2 to 1.0 mm. in diameter. Magnetite, zircon and apatite are present in all the outcrops, and biotite and sillimanite needles are found only in those that have been intruded by the gabbro.

Gabbro and Anorthosite.—There are numerous masses of basic igneous rocks exposed in Kiowa and Comanche counties. In the latter there are three large and seven small isolated masses; the largest exposure is twelve miles long by two and three-quarters miles wide. In Kiowa County there are a dozen small hills and one large mass fourteen miles in length.

The rocks are gabbros, anorthosites, grano-gabbros and quartz-bearing gabbros. The last two varieties are exposed in small areas and are considered to be local phases of the other types. The gabbro and anorthosite also grade imperceptibly into one another and no one sample can be taken as representative of the composition of even a small hill. Most of the basic rocks contain more than 80 per cent labradorite and in some the feldspar content amounts to 96 per cent. For this reason most of them are considered anorthosites.

The texture of the rocks varies from coarse to fine grained, though the majority are coarse and show distinct tabular crystals of feldspar. Some of the outcrops are schistose in appearance, which structure probably was developed during the intrusion, and does not indicate metamorphism. In color the rocks vary from white through gray to black, the dark varieties being the commonest. The coloring matter probably is due to inclusions of magnetite and ilmenite in the labradorite.

The composition of the gabbros and anorthosites is extremely variable, as has been pointed out. In some specimens diallage is the chief ferromagnesium mineral whereas in others, hornblende, augite, or olivine predominate. The common accessory minerals are apatite, titanite, zircon, and magnetite. The magnetite varies from a few specks to as much as six per cent of the rock. This mineral is titaniferous and has been altered partially to leucoxene. The mica inclusions in the labradorite are also titaniferous.

In some exposures the rocks are fresh and unaltered. In

others they have been subjected to hydrothermal alteration and decomposed to such an extent that in places the altered material is loose and friable and is used as a gravel for the local roads. In such rocks the diallage has been changed to chlorite, epidote, and uralitic hornblende. The biotite has been altered to chlorite and the hornblende to epidote and chlorite. Calcite and quartz commonly are present.

The largest mass of anorthosite is in Kiowa County where it forms many of the hills, and the magnetite occurrences are most numerous in this region.

Granophyres.—The acidic rocks were called granites by Taft and by Taylor and generally are known by this name even today. In 1930, however, Hoffman, after microscopic and field studies, called them "granophyres." Granophyres are hypabyssal or dike rocks of granitic composition in which quartz and alkali feldspar to a large extent are intergrown, in a micro-pegmatitic texture.

The granophyres of the Wichitas have been subdivided into five types by Hoffman, as indicated in the previous table. These rocks, however, are quite similar in composition although they differ somewhat in their textures and in the minor mineral constituents. As a group they are acidic and composed essentially of quartz and alkali-feldspar. The ferromagnesium minerals, hornblende and biotite, rarely exceed 8 per cent. Zircon, apatite, titanite, and magnetite are common accessories. Riebeckite also is present in some of the Quanah granophyre outcrops. The magnetite is titaniferous and has been partly altered to leucoxene. In some specimens the biotite and hornblende have been changed to chlorite, and the feldspars in some localities have been altered to kaolin and sericite. Other specimens are comparatively fresh and unaltered.

The granophyres are younger than the anorthosite-gabbros. The age relationship of the various granophyres to one another is not clear in all cases. The sequence given in the table is taken from Hoffman and represents the best information available at this time.

Hoffman believes that the granophyres were intruded as sills probably thousands of feet thick and at various depths below the surface. He also believes that the Davidson, Carlton, and Saddle Mountain granophyres were probably extrusive or near surface phases of the Lugert granophyre.

Dike Rocks.—The formation of dikes of various types, including aplites, pegmatites, diabases, and quartz dikes, was the latest phase of igneous activity. These rocks are numerous and cut the anorthosite and granophyres. Magnetite is present as an accessory mineral in all of the dike rocks.

All the igneous rocks of the area probably are differentiates of the same parent magma. In this connection Hoffman[5] writes:

> Both the basic and acidic intrusions in the Wichita Mountains may be the differentiates of a deep-seated gabbroic magma. They are closely related in age as indicated by the absence of chilling phenomena along the contacts. The granophyres followed the gabbros while they were still quite hot.
>
> The first to be intruded was the gabbro. It was apparently an anorthositic phase of the deep-seated source as it is feldspar rich. Some further differentiation took place after the injection, which tended to accumulate the anorthosite in the upper portion of the mass and the gabbro in the lower. Shortly afterwards the granophyres were intruded as a series of sills in more or less rapid succession. The Davidson, Carlton and Saddle Mountain were perhaps extrusive or near surface phases of the Lugert. They are all closely related in composition but the first three are fine-grained to porphyritic. The diabase dikes were intruded after the Lugert. The Quanah was last, and deeper than the preceding. It is more coarsely grained than the other granophyres. The aplite dikes which intersect the Quanah and the older rocks were formed considerably later, most likely after the rocks had time to cool. They are fine-grained and cut the Quanah which is very coarse-grained.

Paleozoic Sediments.—The early Paleozoic rocks form a discontinuous rim around the eastern end of the Wichita Mountains. These rocks are subdivided into Reagan sandstone, Arbuckle limestone, Simpson group, and Viola limestone.

The Reagan sandstone is upper Cambrian and rests upon the eroded uneven surface of the Pre-Cambrian igneous rocks, from which most of its material has been derived. It is exposed in four areas in this region and is approximately 300 feet thick. It is composed of arkose (granite wash), hard and soft sandstone, shales, and limestone. Glauconite is present in various beds.

[5] Idem, p. 48.

Exposures of the Arbuckle, Simpson, and Viola are found in this area but will not be discussed as they are not pertinent to the discussion. Readers desiring further details concerning these rocks are referred to the bulletins by Taff and others.

Permian red beds (Wichita-Clear Fork formations) form a mantle on many of the flats underlain by the Pre-Cambrian igneous rocks, and also overlap the eroded edges of the lower Paleozoic rocks, on the flanks of the mountains. They are composed of gravels, sandstones and conglomerates, which rocks contain a considerable amount of igneous fragments and also some carbonate. Titaniferous magnetite is present and in some places it is quite abundant as black sand.

THE MAGNETITE DEPOSITS.

Small fragments of magnetite are common in all the anorthosite-gabbro areas. Such fragments have been weathered free from the rock and are scattered over the ground. The magnetite also may occur in more or less concentrated masses intimately associated with the basic igneous rocks. Some of these latter deposits have been tested by pits, trenches, and shafts but none of these workings are extensive. Magnetite is ubiquitous throughout the anorthosite exposures but no large mass of this mineral has been uncovered. Whether or not large deposits occur is a question that can be answered only by a magnetometer survey or by core drilling. The surface exposures of the magnetite are irregular and in all probability the shape of the mass below the surface also is erratic. Therefore, estimates as to the size of the deposits cannot be made with the data at present available.

Only detailed surface mapping of the entire area would make possible the enumeration of all the deposits. Even if this were done, it would be difficult to draw the line between the anorthosites containing a considerable amount of magnetite, yet of no economic importance, and those that might have some commercial possibilities. Therefore, in this preliminary report only a few type occurrences of the magnetite will be described and no pretense at completeness is made.

SE¼ sec. 4, T. 4 N., R. 17 W., Kiowa County (No. 1, Fig. 1).—Magnetite fragments are abundant in a zone of hydrothermally altered anorthosite. This zone is approximately 40 feet wide and is exposed along the west bank of a creek. The dimensions of the deposit are unknown as it is not exposed except on the creek bank. However, it seems to be larger than most of the magnetite deposits of the region. A granophyre intrudes the anorthosite close to the iron ore and the hydrothermal alteration undoubtedly has been caused by magmatic solutions from this intrusion.

SE¼ SE¼ SE¼ sec. 18, T. 4 N., R. 16 W., Kiowa County (No. 2).—Magnetite fragments are found in an old prospect pit 6 feet deep in the anorthosite. This magnetite is a natural lodestone. There has been considerable hydrothermal alteration and the rock has become loose and friable. Quartz stringers, and also some malachite, are present.

NW¼ SW¼ sec. 24, T. 4 N., R. 16 W., Kiowa County (No. 3).—Loose magnetite fragments are abundant over an area of 5 acres. The mineral is associated with loose anorthosite fragments and probably is a residual product from the weathering of the igneous rock.

NW¼ sec. 29, T. 4 N., R. 16 W., Kiowa County (No. 4).—Pieces of magnetite are scattered over an area of 50 × 50 yards on the side of a hill. The mineral is associated with anorthosite fragments.

NW¼ sec. 33, T. 4 N., R. 16 W., Kiowa County (No. 5).—Magnetite fragments are scattered over an area of 10 square feet. A shaft nearby shows the magnetite associated with anorthosite.

SE¼ sec. 4, T. 3 N., R. 13 W., Comanche County (No. 6).—Magnetite is found in a fissured zone at the contact of anorthosite and granophyre. Some of the iron mineral also is disseminated throughout the anorthosite. There has been some oxidation with the production of limonite, hematite, and leucoxene.

NW¼ sec. 21, T. 3 N., R. 14 W., Comanche County (No. 7).

—A shaft, 100 feet deep, has been sunk at the contact of anorthosite and granophyre and an inspection of the material from this opening shows magnetite, sphalerite and galena. Considerable hydrothermal alteration is evident and the sulphide minerals probably were introduced by magmatic solutions from the granophyre.

Summary.—In all deposits there is clear evidence that the magnetite is associated with anorthosite. Even where the surface rocks are Permian, the presence of labradorite and other igneous minerals indicates the close connection between the magnetite and the anorthosite, and it is evident that the basic igneous rock underlies the sediments. In two of the deposits the magnetite is located at the contact of anorthosite and granophyre. In all cases there has been some hydrothermal alteration and the introduction of quartz and other minerals.

All samples of the ore show some degree of weathering. The magnetite is partially altered to limonite and hematite and the ilmenite is partially altered to leucoxene and limonite. In general, the deposits have unknown boundaries that probably are irregular.

The magnetite occurs as fine to coarse fragments in the deposits. Poorly defined octahedral crystals eight inches wide have been found but generally the crystals are small and indistinct. Some of the material is a natural lodestone but most of it is not of this type. In general, it is somewhat altered on the outside to limonite and hematite with a resulting brown or yellow coating, whereas the inside is black and unaltered. Some specimens show a small amount of chalcopyrite, which may be partially altered to malachite. In others, galena and sphalerite are present and in most samples some quartz can be detected. This latter mineral is present as transparent small crystals or as chalcedony. In all specimens, typical anorthosite minerals such as labradorite are noticeable.

CHEMICAL CHARACTER OF THE ORE.

Three complete analyses of massive magnetite are given below. The specimens analyzed were hand specimens of magnetite containing few impurities.

	No. 1.	No. 2.	No. 3.
SiO_2	2.52%	2.20%	13.56%
FeO	5.34	10.43	31.64
Fe_2O_3	71.68	61.95	27.35
Al_2O_3	8.61	7.53	2.76
MnO_2	trace	trace	0.30
TiO_2	10.93	16.05	14.30
CaO	——	——	0.90
MgO	1.47	2.83	9.02
P_2O_5	1.07	trace	——
K_2O	——	——	0.40
Na_2O	——	——	0.62
S	——	——	——
CoO	——	——	——
NiO	——	——	——
Cr_2O_3	——	——	——
Total	101.62	100.99	100.85
Total Fe	54.28	51.44	43.70

Three partial analyses also were made on hand samples from various deposits, though in these the samples were selected as typical of the average ore.

	No. 4.	No. 5.	No. 6.
TiO_2	——	5.20%	4.40%
Fe	19.80%	13.70	11.50
Insoluble residue *	56.60	75.34	73.00

No. 1. NW¼ sec. 24, T. 4 N., R. 16 W.; No. 2. SW¼ sec. 7, T. 4 N., R. 16 W.; No. 3. SE¼ sec. 14, T. 4 N., R. 17 W.; No. 4. Sec. 21, T. 3 N., R. 14 W.; No. 5. S½ SE¼ NW¼ sec. 33, T. 4 N., R. 16 W.; No. 6. NW¼ SE¼ NW¼ sec. 4, T. 3 N., R. 13 W.

Analyses made by S. G. English and H. Sudduth, chemists for the Oklahoma Geological Survey.

* Insoluble residue after treating with concentrated HCl, HNO_3, and H_2SO_4. The residue is mainly undecomposed silicates.

MICROSCOPIC CHARACTER OF THE ORE.

A polished specimen was etched with cold 6 N. hydrochloric acid for two hours. The acid attacks the magnetite more rapidly than the ilmenite and, furthermore, the former is darker than the ilmenite and, therefore, these two minerals can easily be distinguished after acid treatment (Fig. 2).

Ilmenite is present in the ore as small crystals with rectangular outlines and also as irregular elongated fragments. In part, it

is intimately intergrown, as minute stringers 1 mm. long or smaller, along the octahedral planes of the magnetite crystals. These octahedral planes show as a triangular network on the surface of the polished magnetite.

Minor amounts of diallage, biotite, and hornblende were noticed in thin sections. These minerals are partially altered to chlorite. A few grains and stringers of quartz were detected and also a little malachite and azurite.

The location of ilmenite along the octahedral planes of the magnetite has been explained by exsolution. It is assumed that these two minerals form miscible solutions at the high temperatures at which they were formed. On cooling, the ilmenite and magnetite are not completely miscible and consequently some of the ilmenite separates out along the octahedral planes of the magnetite.

A study of the chemical analyses and polished specimens and thin sections show the following points:

1. The magnetite is titaniferous.

2. Analyses Nos. 1 and 2 show insufficient ferrous iron for the titanium to be present as ilmenite, therefore the ilmenite has in part been altered to hematite, limonite and leucoxene. These minerals can be observed in the polished and hand specimens.

3. In the same specimens the low ferrous content shows that the magnetite has been partially altered to hematite and limonite.

4. In analysis No. 3 the ferrous content is high, indicating that there has been very little oxidation of the material.

5. The magnesium and aluminum are present as silicates, chiefly pyroxenes and their alteration products.

6. The titanium oxide content varies from 0 to 16.05 per cent. In sample No. 4, no titanium is present but this specimen probably represents only a local phase of the ore. Furthermore, this sample and Nos. 5 and 6 are high in silicates and therefore little titanium would be expected.

The variable chemical character of the deposits is indicated by these analyses. The amount of iron varies inversely with the quantity of titanium and also, of course, the more rock minerals present, the less the iron and titanium content.

ORIGIN OF THE MAGNETITE DEPOSITS.

This study has not been sufficiently detailed for the author to form definite ideas concerning the origin of these deposits. However, the similarities of these occurrences with those of the titaniferous magnetites in other parts of the United States, which generally are considered to be magmatic segregation deposits, strongly suggest that these iron ores also belong to this class.

In all probability the titaniferous magnetite was a magmatic segregation product of the magma that yielded the anorthosite and granophyres. The presence of magnetite in all the igneous rocks of the area and the intimate association of the iron mineral with the anorthosite support this hypothesis. The irregular shape of the deposits and their erratic distribution further corroborate this interpretation. Undoubtedly some hydrothermal action has taken place, for chalcopyrite, galena, sphalerite, and quartz were formed by deposition from magmatic solutions emanating from the granophyres. The intense hydrothermal alteration of the anorthosite in some localities also supports this idea. At present no information is available concerning the paragenesis of the ore and it is impossible to give the age relationships of the various minerals. It may be that some of the deposits were developed by magmatic segregation of the magnetite from the anorthosite magma and later the ores have been subjected to hydrothermal alteration.

Surface weathering has altered the chalcopyrite to malachite, azurite, and limonite; the magnetite to hematite and limonite; and the ilmenite to leucoxene and limonite.

ECONOMIC POSSIBILITIES OF THE MAGNETITE DEPOSITS.

It is possible that detailed studies of the area might uncover ore bodies of magnetite sufficiently large for mining purposes providing that other conditions were favorable. Unfortunately, at the present time, the iron industry is prejudiced against titaniferous iron ores and they are generally not acceptable if the titanium content is more than one per cent. The ores of the Wichitas have a variable titanium content but the average of six analyses,

is 8.40 per cent TiO_2 and consequently at the present time they have no economic value.

Singewald [6] has experimented on the separation of ilmenite from magnetite by electromagnetic methods in ores from various localities and in all tests he reduced the titanium content considerably but not sufficiently to warrant their mining. The intimate intermixture of the two minerals and especially the presence of ilmenite along the octahedral lines of magnetite, prevents a complete separation. Furthermore, the magnetite probably contains some isomorphous titanium.

The prejudice against titaniferous iron ores exists because such material requires an excessive amount of fuel to reduce them and also that an infusible titanium compound develops, which accumulates and chokes the furnace. This makes the reduction expensive, and it also requires more skilled labor to manipulate the furnaces. Since large quantities of hematite ore, free from titanium, are available, the titaniferous ones are not utilized.

Experiments by Stansfield [7] and others with the electric furnace have given promising results and it is possible that future years may bring a change in the status of these ores. The absence of sulphur is a point in their favor and also a certain amount of titanium is beneficial in the manufacture of special alloys such as tool steels.

There are several titaniferous-magnetite deposits known in the United States. Some of these contain large bodies of ore and are located advantageously with respect to coke and industrial centers. It is likely that these will be developed before the less favorably situated ones, such as those of the Wichita region.

MAGNETITE SANDS OF THE WICHITA MOUNTAINS.

The sands of the Wichita area contain considerable titaniferous magnetite which, of course, has been derived from the anorthosites by weathering. In places, magnetite is rather abundant in

[6] Singewald, J. T., Jr.: The titaniferous iron ores in the United States. U. S. Bur. of Mines, Bull. 64: 18–24, 1913.

[7] Stansfield, Alfred: Electric smelting of titaniferous ores. Can. Min. Jour., 33: 448–449, 1912.

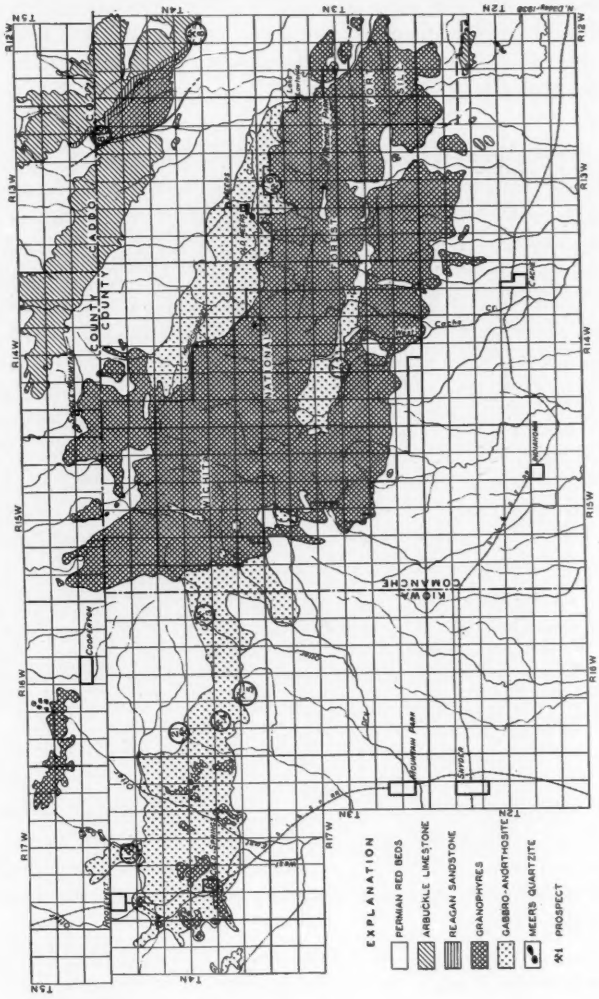

EXPLANATION
PERMIAN RED BEDS
ARBUCKLE LIMESTONE
REAGAN SANDSTONE
GRANOPHYRES
GABBRO-ANORTHOSITE
MEERS QUARTZITE
PROSPECT
COMANCHE
KIOWA
COUNTY
CADDO
COUNTY

FIG. 1.

the sands. The iron mineral is found in the Permian sediments on the flanks of the mountains and also in the Tertiary and Recent sediments in the central part of the region. Such deposits have no commercial possibilities.

HEMATITE DEPOSITS OF THE WICHITA MOUNTAINS.

The hematite deposits of the Wichitas are found in the Reagan sandstone and are not related genetically to the magnetite ores of the area, though it is possible that the latter deposits may have been one source of the iron in the hematite. The Reagan sandstone in this area is composed of well-rounded conglomeratic material a few feet thick at the base. This is overlain by a bedded sandstone containing a few layers of clay. Some of the beds are stained black by manganese oxides and many contain considerable glauconite. The hematite ores occur as a bedded deposit in a sandstone member about forty feet above the base of the formation.

The only hematite occurrence of any size in the area is located in T. 4 N., Rs. 12 and 13 W. (No. 8, Fig. 1). Williams[8] has described this deposit as follows:

> A considerable body of iron ore (Fe_2O_3) occurs in the Reagan about forty feet above its base. The rocks at this point dip at an average angle of 30° to the northeast with a width of ore body of twenty-one feet. The ore is exposed for a distance of at least a mile in a general northwest-southeast direction. The ore body is nine feet thick three-fourths of a mile southeast of the principal mine shaft.

Chemical analyses of samples from different parts of the deposit show considerable variation in the iron content. Shead[9] reports analyses of the ore as follows: "Hematite, secs. 1 and 2, T. 4 N., R. 13 W., and secs. 7, 17, 20, 21, T. 4 N., R. 12 W., Comanche County. Ore body is 200 feet wide, runs 35 per cent Fe at the east end of the outcrop and 7 per cent Fe at the fault in section 7."

[8] Williams, A. J.: Hematite in the Reagan sandstone along the northeast edge of the Wichita Mountains and in the Arbuckle Mountains. Proc. Okla. Acad. Sci., XV: 82, 1935.

[9] Shead, A. C.: Chemical analyses of Oklahoma raw materials. Okla. Geol. Surv. Bull. 14: 29, 1929.

A representative sample was taken of a cut from which a few tons of ore were shipped some years ago. This material was analyzed in the Oklahoma Geological Survey laboratory as follows.* SiO_2 63.22 per cent; Al_2O_3 4.42; FeO 1.18; Fe_2O_3 30.80;

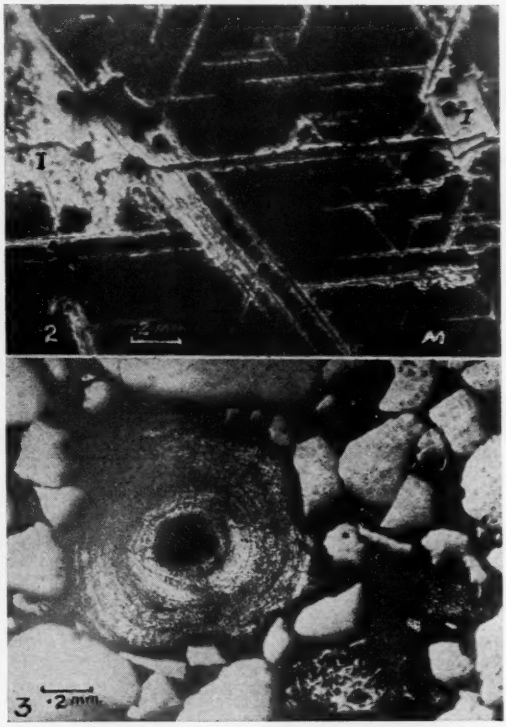


FIG. 2. Polished specimen of the ore showing ilmenite (I) along the octahedral planes of the magnetite (M). A rectangular crystal of ilmenite (I) also is shown.

FIG. 3. Polished specimen of hematite showing sand grains and a hematite oölite. The background is bakelite.

* Analyzed by H. Sudduth, Chemist, Oklahoma Geological Survey; sample from sec. 17, T. 4 n., R. 12 W.

MnO_2 trace; TiO_2 trace; CaO 0.19; MgO 0.36; K_2O 0.53; Na_2O 0.44; P_2O_5 0.41; CO_2 —; total 101.55.

A study of thin sections and polished specimens of the ore shows it to be essentially a sandstone with considerable hematite in the cement. The sand is rounded to sub-angular in shape and varies in size from 0.1 to 0.75 mm. in diameter. Oölitic hematite grains are numerous. These are more or less rounded and have circular to elliptical cross sections, varying in size from 0.3 to 1.5 mm. in diameter. Many of the oölites have a sand grain in the center, but others have no observable nucleus. The oölites commonly show fine concentric bands (Fig. 3). A green mineral is present as irregular masses both in the oölites and in the cement, between the sand grains. Its index of refraction is 1.64 and therefore it has been labelled chamosite rather than glauconite.

A sample of the ore was treated with concentrated hydrochloric acid, which dissolved the iron oxides. The structure of the oölites, however, was not altered by this treatment, though they became white and translucent. When observed under the microscope these treated oölites were seen to be composed of concentric shells that could be pried apart by a needle. This reaction is similar to that of the Clinton [10] and Wabana iron ores.[11]

Hayes [12] describes the Wichita hematites as follows:

> The spherules, about half a millimeter in diameter, have an onion-like structure consisting of alternate concentric layers of hematite and a green iron silicate resembling chamosite. They are similar to those of the Wabana iron ores of Newfoundland of Ordovician age. Recrystallized hematite with some magnetic iron mineral occurs interstially between the sand grains and spherules and sparingly within the spherules.

Williams [13] believes that the iron of the hematite was derived from the weathering of the glauconite of the Reagan sandstone. He writes:

> The evidence points to the conclusion that upon breaking down of the glauconite, the potassium and part of the silica was carried away in solu-

[10] Smyth, C. H., Jr.: On Clinton iron ore. Amer. Jour. Sci. 3d. Ser., 43: 487–496, 1892.

[11] Hayes, A. O.: Wabana iron ores. Can. Geol. Surv., Mem. 78: 70, 1915.

[12] Hayes, A. O.: Cambrian oölitic hematite in the Reagan sandstone of Oklahoma. Abst. Bull. Geol. Soc. Amer. 44: 86–87, 1933.

[13] Williams, A. J.: *Op. cit.*, p. 82.

tion. Part of the remaining silica was used in cementing the quartzitic sandstone. The iron was united with the oxygen to form hematite (Fe_2O_3). In the case of the ore body under consideration, the original glauconite at this point was purer, or iron, leached from other parts of the formation, was added. That the latter may have been the case is strongly suggested by the porous condition of the quartzitic sandstone.

Williams' interpretation would date the formation of the ores as later than the Reagan sandstone, that is, they would be epigenetic. With this conclusion the author cannot entirely agree although the present study is of such a preliminary nature that the question cannot be considered as settled. The author believes that the chamosite and most of the hematite were formed contemporaneously with the Reagan sandstone, that is, they are mainly syngenetic. However, there may have been some oxidation of the chamosite since Reagan time and thus part of the hematite may belong to a later generation. The points suggesting the syngenetic origin of most of the ores are:

1. The ores are confined to definite beds in the Reagan sandstone.

2. Many of the oölites that contain chamosite and hematite are flattened so that they resemble discs. In such oölites the flattened surface is parallel to the bedding plane of the sediments, which relationship suggests that the oölites, while still soft, were flattened by the weight of the overlying sediments. If this is true, it follows that the oölites are contemporaneous with the sediments and since these oölites are composed of chamosite and hematite, these minerals must have been formed in the Reagan sea. It is possible that part of the hematite in the oölites is an alteration product of the chamosite, but at least the chamosite and part of the hematite would be contemporaneous with the sediments.

Several attempts have been made to mine the hematite ores. The mining, however, has been on a small scale and has not involved any detailed surveys of the deposits nor systematic experiments on the best methods of utilizing the material. At one time, paint was manufactured at the workings by crushing the ores and treating them with oils. Some tons of ore also were shipped to Oklahoma City and treated in a similar manner. The large con-

tent of sand in the hematite gave the paint excellent adhering properties and it was hoped that it could be used for shingle paint and other similar purposes. For some reason these activities were abandoned after a short time and there has been no mining at these deposits during the last few years. It is possible that paint pigment might be obtained profitably from these ores, especially if the hematite was first concentrated.

There seems little possibility that the hematite can be utilized at the present time as a source of iron as the percentage of this element in the ore is much too low for profitable exploitation.

UNIVERSITY OF OKLAHOMA,
NORMAN, OKLA.,
Sept. 15, 1938.

MINERAL RESOURCES OF THE CHEMICAL INDUSTRIES.

R. N. KELLER AND T. T. QUIRKE.

ABSTRACT.

The geologic origin of the constituents of one hundred and fifty important industrial chemicals has been determined. The selection was made on the basis of quantity consumption, and their entry into a large variety of essential products. In the majority of cases one chemical is produced by the use of a group of other chemicals; therefore, the same raw materials enter into the manufacture of many industrial chemicals. This study shows the overwhelming importance of hydrocarbons, sulphur and sulphides, the haloid salts, and limestone.

A point sharply brought out as a result of the study is the highly developed inter-dependence of all branches of the chemical industry, resulting in a definite trend towards the vertical type of industrial development, which includes the basic mining industries.

INTRODUCTION.

ALTHOUGH it is well known that the chemical industries depend on mineral resources for their raw materials, the fact that the great bulk of important chemicals is manufactured from a relatively few minerals has not been fully appreciated; neither has it been generally recognized that a host of contributing chemicals may be involved in the preparation of a single industrial chemical.

This article summarizes a study which was made for the purpose of tracing some of the important chemicals back to their geologic raw materials. One hundred and fifty chemicals produced in this country were selected for investigation and these are listed in Table I. These chemicals were chosen primarily on the basis of their production values and their general usefulness to chemical industry.

TABLE I.

One Hundred Fifty Important Industrial Chemicals

1. Acetanilide
2. Acetic acid
3. Acetic anhydride
4. Acetone
5. Acetylene
6. Alum, ammonia
7. Alum, chrome
8. Alum, potash
9. Aluminum chlorides
10. Aluminum oxide
11. Aluminum sodium sulphate
12. Aluminum stearate
13. Aluminum sulphate
14. Ammonia
15. Ammonium chloride
16. Ammonium nitrate
17. Ammonium phosphates
18. Ammonium sulphates
19. Amyl acetate
20. Amyl alcohol
21. Aniline
22. Anthracene
23. Antimony oxide
24. Arsenic, white
25. Barium sulphate
26. Benzene
27. Bismuth subnitrate
28. Bleaching powder
29. Borax
30. Boric acid
31. Bromine
32. Butyl acetate
33. Butyl alcohol
34. Calcium acetate
35. Calcium arsenate
36. Calcium carbide
37. Calcium carbonate
38. Calcium chlorides
39. Calcium cyanamide
40. Calcium fluoride
41. Calcium hypochlorite
42. Calcium phosphates
43. Calcium sulphates
44. Camphor
45. Carbon (bone black, lampblack, carbon black, charcoal, activated carbon)
46. Carbon dioxide
47. Carbon disulphide
48. Carbon tetrachloride
49. Cellulose acetate
50. Cellulose nitrate
51. Chlorine
52. Chloroform
53. Chromic acid
54. Chromium oxide
55. Citric acid
56. Coke
57. Copper cyanide
58. Copper sulphates
59. Epsom salts
60. Ethyl acetate
61. Ethyl alcohol
62. Ethyl ether
63. Ethylene
64. Ethylene glycol
65. Formaldehyde
66. Glycerine
67. Glyceryl nitrate
68. Hydrochloric acid
69. Hydrocyanic acid
70. Hydrofluoric acid
71. Hydrogen
72. Hydrogen peroxide
73. Indigo
74. Iodine
75. Iron chlorides
76. Iron oxides
77. Iron sulphates
78. Lactic acid
79. Lead acetate
80. Lead arsenate
81. Lead chromate
82. Lead oxides
83. Lead sulphates
84. Lead tetraethyl
85. Lime
86. Magnesium carbonate

87. Manganese dioxide
88. Mercury chlorides
89. Mercury
90. Methyl alcohol
91. Methyl chloride
92. Milk of magnesia
93. Naphthalene
94. Naphthol
95. Nitric acid
96. Nitrobenzene
97. Nitrous oxide
98. Oleic acid
99. Oxalic acid
100. Oxygen
101. Phenol
102. Phosphoric acid
103. Phthalic anhydride
104. Potassium hydrogen tartrate
105. Potassium chlorate
106. Potassium chloride
107. Potassium dichromate
108. Potassium ferrocyanide
109. Potassium hydroxide
110. Potassium iodide
111. Potassium permanganate
112. Silica
113. Silica gel
114. Silver nitrate
115. Sodium aluminates
116. Sodium antimonate
117. Sodium benzoate
118. Sodium carbonates
119. Sodium chloride
120. Sodium citrate
121. Sodium cyanide
122. Sodium dichromate
123. Sodium hydroxide
124. Sodium hypochlorite
125. Sodium nitrate
126. Sodium nitrite
127. Sodium peroxide
128. Sodium phosphates
129. Sodium silicates
130. Sodium sulphates
131. Sodium sulphide
132. Sodium sulphites
133. Sodium thiosulphate
134. Stearic acid
135. Sulfamic acid
136. Sulphur
137. Sulphur chlorides
138. Sulphur dioxide
139. Sulphuric acid
140. Tannic acid
141. Tartaric acid
142. Tin oxides
143. Tin chlorides
144. Titanium dioxide
145. Toluene
146. Urea
147. Xylene
148. Zinc chloride
149. Zinc oxide
150. Zinc sulphates

METHOD OF PROCEDURE.

In order to facilitate the task of determining the ultimate raw materials for this large group of chemicals, about a dozen important basic chemicals were first traced back to their mineral sources. These basic chemicals are those that figure consistently in the manufacture of other chemicals, and include such substances as sulphuric acid, sodium hydroxide, sodium carbonate, hydrochloric acid, and nitric acid. These having been worked out, the procedure of tracing back the remaining chemicals was simplified considerably. Wherever one of these basic chemicals

was used in the manufacture of another chemical the analysis along that particular branch could be discontinued. The ultimate raw materials of the basic chemical, as previously determined, end that line of analysis. Only chemicals not previously encountered remained to be traced out, either to ultimate raw materials or to chemicals whose ultimate raw materials had already been determined. By following such a plan it is apparent that with each addition to the list of chemicals for which the ultimate raw materials were already known there was a corresponding decrease in the frequency with which new chemicals were encountered as raw materials.

The method of investigation may be illustrated by a detailed consideration of the important industrial chemical, sodium carbonate. This chemical is produced by three different manufacturing processes, and a small quantity is recovered directly from naturally occurring brines. Since throughout this study it has been the plan to take into account all of the important methods employed for the production of any chemical, each of these processes will be considered in turn. The most important, the Solvay process, consists essentially of first precipitating sodium bicarbonate from an ammoniacal solution of ordinary salt by the addition of carbon dioxide. Sodium carbonate is obtained by the calcination of the sodium bicarbonate. The ammonia, which remains in solution as ammonium chloride, is recovered by adding calcium oxide and then heating the solution. Calcium chloride is precipitated and is a by-product, while most of the ammonia is returned to the process. The immediate chemical raw materials of this process would be, then, sodium chloride, ammonia, lime, and carbon dioxide, while the ultimate raw materials would be the ultimate raw materials of these four substances. The Le Blanc process would add to this list only coal and the raw materials of sulphuric acid. Since, however, this process is practically never employed in this country, it is omitted from these considerations. The electrolytic process, using sodium chloride and carbon dioxide, adds no new raw materials to the list. The raw materials of sodium carbonate may now be listed as follows:

Sodium carbonate	Brines
	Salt
	Lime
	Carbon dioxide
	Ammonia

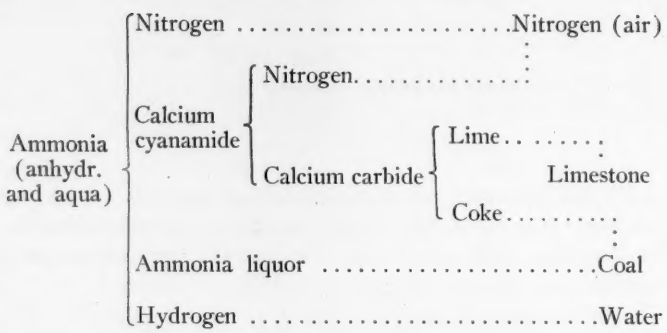
Of this group of raw materials, brines and salt are natural products; lime and carbon dioxide are obtained by the calcination of limestone, while more steps are involved between ammonia and its ultimate raw materials.

The treatment of ammonia will be continued in detail. The sources of ammonia (anhydrous and aqua) and materials used in its manufacture can be listed as follows:

Ammonia (anhydrous and aqua)	Ammonia liquors
	Nitrogen
	Hydrogen
	Calcium cyanamide
	Catalysts, catalyst supports, etc.
	Peat, bones, and animal refuse
	Beet sugar industry, etc.

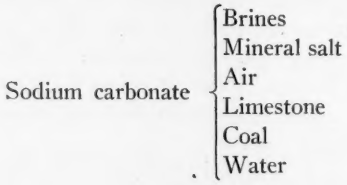
The source of ammonia liquors is coal gas, or simply coal. Nitrogen comes from the air, hydrogen from water, and so on. Since catalysts, catalyst supports, etc., are in general not consumed during the process and there is considerable latitude in some processes as to the type of catalyst employed, and inasmuch as some of the catalysts used are trade secrets, it was deemed advisable not to consider substances used in such capacities as contributing materials of manufacture. Also items such as peat, bones, animal refuse, sugar beets, etc., were not considered in this study as raw materials, consideration being limited as far as possible to mineral materials. These limitations are quite arbitrary, of course, but are consistent with the purposes of the study.

The method of obtaining the ultimate raw materials of ammonia can be summarized in chart form as follows:



Accordingly, the ultimate raw materials of ammonia are nitrogen of the air, limestone, coal and water.

The ultimate raw materials of sodium carbonate, as obtained by the preceding method, can now be listed:



This same scheme may also be applied to sodium chloride which is intended for food purposes. Natural salt which is to be used as a raw material in the preparation of sodium carbonate requires a preliminary treatment with only carbon dioxide for the purpose of removing undesirable substances, but the procedure is more complicated when the salt is to be used for food purposes. Deleterious materials are removed, and substances are added to counteract the hygroscopic character of certain impurities. There is no standard procedure, but the essential chemicals employed in these capacities are indicated in the following list. This list also includes the sources of the sodium chloride. The sodium chloride industry might be said to depend, then, on the following materials:

Sodium chloride	Brines
	Mineral salt
	Hydrochloric acid
	Trisodium phosphate
	Sodium carbonate
	Lime
	Sodium hydroxide
	Carbon dioxide
	Sodium sulphate
	Magnesium carbonate
	Starch

All items but the first two in this list depend, in turn, on other substances. The same procedure can be followed for each of these as outlined above for sodium carbonate, and it is quite apparent that a diagrammatic outline of such a procedure would lead into a ramification of chemicals. Omitting the steps involved, the following materials are obtained as ultimate geologic raw materials of the sodium chloride which is to be used for food purposes:

Air	Limestone	Potassium minerals
Aluminum minerals	Magnesium minerals	Saltpeter
Brines	Mineral salt	Sand
Coal	Natural gas	Sulphur
Fluorine minerals	Petroleum	Sulphide ores
Gypsum	Phosphate rock	Water

RESULTS OF PROCEDURE.

Table II shows the ultimate geologic raw materials of all the chemicals in Table I and is a composite list of the individual lists for these chemicals. These individual lists of ultimate geologic raw materials were obtained in the same manner as previously outlined for sodium carbonate and sodium chloride.

TABLE II.

THE ULTIMATE GEOLOGIC RAW MATERIALS FOR ONE HUNDRED FIFTY IMPORTANT INDUSTRIAL CHEMICALS.

	Index Numbers.*
1. Water	99
2. Air	96
3. Coal	91
4. Sulphur	88
5. Mineral salt	75
6. Limestone	63
7. Sulphide ores	32
8. Brines	24
9. Petroleum	23
10. Natural gas	16
11. Saltpeter	13
12. Potassium minerals	11
13. Gypsum	10
14. Lead ores	9
15. Sand	9
16. Aluminum minerals	8
17. Chromium ores	7
18. Iron ores	6
19. Phosphate rock	6
20. Sea water	5
21. Copper ores	4
22. Flourine minerals	4
23. Arsenic minerals	3
24. Magnesium minerals	3
25. Mercury ores	3
26. Zinc ores	3
27. Antimony minerals	2
28. Barium minerals	2
29. Boron minerals	2
30. Manganese ores	2
31. Tin ores	2
32. Bismuth minerals	1
33. Silver ores	1
34. Titanium ores	1

* The index numbers indicate relative frequency in use.

The index numbers in Table II following the names of the raw materials indicate the number of times each particular raw material was employed in the actual manufacture, not in the purifi-

cation or treatment, of the chemicals in Table I. For example, all of the substances in the list of ultimate raw materials for sodium carbonate were used in arriving at these numbers, but only brines and mineral salt were used from the list for sodium chloride. The remaining substances in the list for sodium chloride are employed in making chemicals that are used to purify or treat the sodium chloride and are not actually involved in any manufacturing steps. Although these index numbers in Table II are not definite quantitative indicators, they are of significance.

It may also be pointed out that starting with only the raw materials in Table II the list of chemicals of Table I could be extended almost indefinitely. This is especially true with respect to organic chemicals.

CONCLUSIONS.

The majority of the most important industrial chemicals depends upon a comparatively small group of mineral resources for raw materials. The production of a single chemical may involve, in the aggregate, many other chemicals, processes, and raw materials. Scarcely any chemical plant or any one division of chemical industry is a complete entity in itself. All are interdependent to a greater or less degree. A product of one company may be a raw material of another company.

This extreme complexity and interdependency probably has been the factor that has stimulated not so much a horizontal as a vertical type of development in the large chemical corporations. In other words, there is now a distinct tendency toward control by individual companies of virtually all of the stages in the preparation of chemicals and chemical products, from owning the mineral resources to marketing the final products. By-products are being utilized on the spot; in fact, the term "by-product" is rapidly losing significance.

Thus, a vertical development is the natural result of the sound business policy of making every business as independent of outside interests as possible. The mineral producer may antici-

pate the general extension of financial controls which include both fabrication of mineral products and production of raw materials.

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GEOLOGIC PARALLELS: HOG MOUNTAIN, ALABAMA, AND PARACALE, PHILIPPINE ISLANDS.

EDWARD WISSER.

ABSTRACT.

Hypogene epigenetic ore deposits are commonly compared in groups based on the so-called genetic scheme of classification. Such correlation is of value in studies of the physical chemistry of ore deposition; but from the standpoint of the searcher for ore, mining districts should be compared on the basis of any shared features even remotely connected with the localization of ore shoots. Comparison of the hypothermal Hog Mountain deposits with the shallower-type Paracale deposits brings out interesting similarities in structure and ore control, and leads to generalizations concerning some factors that localize ore.

The Hog Mountain and Paracale veins are found to have formed in "tension joints," but not immediately following the formation of the joints. Local ore controls appear to have operated in each camp in the form of intra-mineral fault movements along the veins, and at Hog Mountain transverse to them as well. But the major ore control in each district is thought to have been exercised by a soft schist "trap" above the vein fractures.

Reasons are given why tension joints in general may be likely localities in which to hunt for ore, and the significance to the ore-hunter of the fact that many ore shoots seem to have formed under flat-lying "traps" is discussed.

HYPOGENE epigenetic ore deposits are commonly classified according to the temperature and pressure at which they were formed. Physico-chemical studies have shown that some mineral assemblages and mineral textures found in ore deposits imply formation at high temperature and pressure, whereas other mineral groups and textures indicate deposition at low temperature and pressure. Correlation of these facts with studies in the field shows the pressure and temperature connected with ore formation to be functions of the depth beneath the surface at which ore formed. In general, the greater the depth the higher the pressure and temperature. Thus ore deposits are divided by

Lindgren into epithermal, mesothermal and hypothermal classes not only according to the temperature and pressure at which they were formed, but according to their depths of formation as well.

Because much or all of the original cover above ore deposits has been removed by erosion, the depth at which an ore body was formed is usually impossible to measure in the field. The result is that criteria of mineral assemblage and texture form the most common basis for classifying an ore deposit according to the genetic scheme. In themselves, these criteria applied to an ore deposit may tell whether it formed at shallow, intermediate or great depths beneath the surface existing at the time of mineralization, but they tell nothing more. Deposits within the same division of the genetic classification, the hypothermal deposits for instance, may show similarities other than those of mineral assemblage and texture. But generalizations based on such similarities may depend for their validity on many factors beside the physico-chemical environment in which the deposits were formed. Similarities between hypothermal deposits may involve, for example, structure of the veins. The fact that a certain type of vein structure seems to be typical of many hypothermal deposits by no means implies that similar structure may not be found in epithermal veins.

Ore deposits are grouped to form divisions of a classification; members of a single group share certain features. The use to which a classification can be put depends on the nature of the features that form the basis for the classification. The genetic classification uses the features of mineral assemblage and texture; it may be resorted to for information concerning the physico-chemical environment under which ore formed, but it yields little more.

The searcher for ore usually seeks to answer two questions: Is a given area, as yet unexplored, worth exploring? If it is, where shall he look for ore? To answer these questions he needs to build a classification formed by grouping ore deposits on the basis, not of physical chemistry necessarily, but on that of any features connected with the localization of ore.

No attempt is made in this paper to launch a new classification

of ore deposits. It is enough to point out the desirability of comparing mining districts, or individual ore deposits, on the basis of any shared features. The results of such comparisons should not be merely sets of empirical criteria related to ore localization. They should lead to plausible working hypotheses that explain the features compared. Critical comparisons facilitate the making of valuable generalizations, because phenomena obscure in one camp may be obvious and readily explainable in other camps.

Characteristics, beside those related to physical chemistry, that mining districts may share include: fracture patterns, wall rocks, areal relations of ore shoots or veins to intrusive masses or other features of the regional setting, loci for ore shoots, geologic history of the critical period of mineralization, such as intrusion linked with diastrophism and followed closely by mineralization. Understanding of a district may come piecemeal by comparing it, feature by feature, with analogous districts, even though in one feature only. The Pachuca silver deposits differ from the Butte copper deposits from the standpoint of the physical chemist. The tectonic geologist, on the other hand, sees significant resemblances in the fracture patterns of the two camps, and differences explainable by a common theory of fracture applied to somewhat different settings.

One man cannot study many districts. The geologist must rely on his colleagues for all but a small proportion of his correlation data. He is also often forced to evaluate a district after inadequate field work there. The writer has never visited Hog Mountain, and has spent but four months in Paracale. The present paper, therefore, compares two districts imperfectly known. No claim is made for the correctness of the conclusions reached. It is enough to suggest the possibilities of the structural scheme of comparison, by comparing two districts dissimilar from the standpoint of physical chemistry, but showing resemblances in structure and in the localization of ore.

THE HOG MOUNTAIN AND PARACALE GOLD DISTRICTS COMPARED.

General Geology.

Hog Mountain.[1]—The regional country rock consists of fine-grained graphitic schists of the Paleozoic (?) Wedowee formation. The schist planes at Hog Mountain strike east of north and dip steeply east.

Quartz diorite, exposed on the surface as an area 4,800 feet long and about 1,300 feet wide, has intruded the schist. The major axis of the exposed mass parallels the general strike of the schistosity (Fig. 1*a*). The intrusion is thought to have invaded the schist after most of the deformation that produced the schistosity had taken place, and toward the end of that period of diastrophism.

The east contact of the diorite mass, and the south portion of the west contact, appear to dip steeply east with the schist. The north part of the west contact dips east at only 35°, and the short north contact itself dips 25° south (Fig. 1*a*). These facts suggest a pipe-like or prismatic intrusion whose major axis plunges gently south in a plane parallel to the schistosity. Actually the form is more complex, but the intrusion tends to conform to rather than transgress the schistosity, and its form appears roughly prismatic.

Paracale.[2]—The Paracale-Mambulao gold district lies on the north coast of the island of Luzon, and about 120 miles in a direct line S. 80° E. from Manila. Fig. 1*b* is a partial geologic map of the area.

The regional country rocks include both sediments and intrusives. Miocene (?) shales, sandstones and conglomerates are overlain by andesitic flows, tuffs and agglomerates. Basic igneous rock appears intrusive into both the sediments and the extrusives. In the extreme southwestern part of the district, sills of such rock are plainly seen intruding andesitic flows and ag-

[1] Park, C. F., Jr.: Hog Mountain gold district, Alabama. A. I. M. E. Trans., 115: 209–235, 1935. All data on Hog Mountain are from this paper except where otherwise noted.

[2] Data from the writer's field work and from information supplied by local geologists mentioned under "Acknowledgments."

glomerate. Near the heart of the district relations are not clear, but large exposures of basic rock there seem to be portions of a great sill intruding the sediments. From the few thin-sections examined the basic rock seems to fall into several types, but all

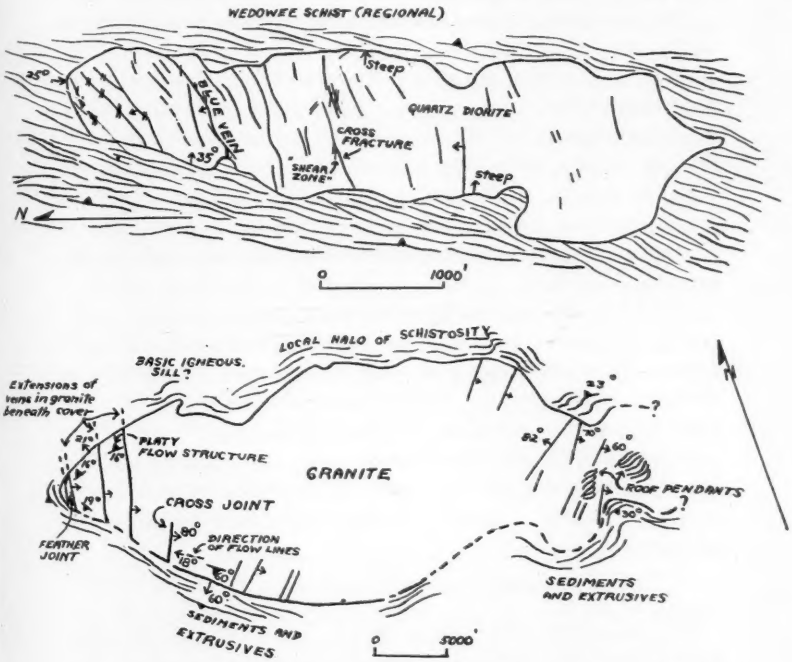

FIG. 1*a* (upper). Geologic map of the Hog Mountain quartz diorite. Adapted from Fig. 1 of paper by C. F. Park, Jr.: Hog Mountain Gold District, Alabama. Trans. A. I. M. E., vol. 115, 1935, pp. 209–225.

FIG. 1*b* (lower). Geologic Sketch Map of the Paracale Granite.

appear to be rather hypabyssal representatives of the gabbro clan.

Coarsed-grained granite, exposed on the surface as an area 5.3 miles long in a direction N. 70° W., and 2.5 miles in maximum width, intruded the sill (?), the sediments, and the extrusive se-

ries. The time of intrusion was probably late Miocene[3] (Fig. 1*b*).

The granite mass extends to unknown depths; but the original shape of its upper part may be reconstructed because the cover has only partly been stripped away.

The top of the granite mass has the shape of an anticline trending N. 70° W. and plunging gently down in that direction (Fig. 1*b*). The granite at the west end of its surface exposure passes beneath its cover exactly as if it were a plunging anticline. The cover here consists of the supposed sill of basic rock; and it is thought to be a sill mainly because of the nature of its contact with the granite, so suggestive of that of a bedded formation domed, but not transgressed, by the intrusion. It is doubtful whether the granite would intrude a body of massive form in this manner.

The cover has been stripped from the central portion of the granite and erosion has cut deeply into it. The north and south contacts dip steeply north and south respectively. The intrusion, therefore, as deeply as exposed, resembles consistently an anticline, with gently arched top and steep flanks.

A halo of schistosity was formed in the wall rocks around the intrusive, traversing the basic sill (?), the sediments, and the extrusive series alike. Away from the granite these rocks are not schistose.

Structures Within the Intrusives.

Hog Mountain.—The quartz diorite seems to lack well developed primary flow structures,[4] but it is intensely fractured (Fig. 1*a*).

In the south part of the exposure the dominant fractures strike nearly east; here the west and east contacts dip steeply. In the north part, the strike of the fractures swings to the northeast; here the west contact dips flatly, while the east contact seems to

[3] Smith, W. D.: Geology and mineral resources of the Philippine Islands. Manila Bur. of Sci., Pub. 19: 416, 1924.

[4] Balk, Robert: Structural behavior of igneous rocks. G. S. A. Mem. 5: 7–25, 1937.

retain its steep dip. Nearly all the fractures dip north at 60° or more. The bottom surface of the diorite prismoid dips 25° S., so that the north-dipping fractures are roughly perpendicular to this bottom surface (Fig. 2; footnote 1).

Less evident is the fact that the fractures are also nearly perpendicular to that segment of the west contact against which they abut. It may be shown by descriptive geometry that the northeast fractures, in the north part of the mass make a true angle of about 85° with the flat-dipping segment of the west contact there. Farther south, where the fractures strike nearly east, they obviously make nearly a right angle in space with the steep-dipping segment of the west contact in that area.

The fractures are, therefore, perpendicular to two sides of the diorite prismoid, the west and bottom sides; they are not far from perpendicular to the east side except at the extreme north end. The upper side has been removed by erosion, but with reference to the remaining three sides, the fractures are properly termed cross fractures, since they lie perpendicular to the major axis of the prismoid as determined by these three sides.

The cross fractures are limited strictly to the diorite. A set of discontinuous fractures, called "shear zones" develops mainly in the diorite, but in places in the schist. The shear zones strike east and dip north, so that they make small angles with the cross joints. They also form principally near cross joints, it seems, as short branches or as minor faults crossing and displacing the cross joints but dying out quickly on either side of the cross fractures they displace. The shear zones may be more numerous in the north part of the diorite mass, where the cross fractures are crooked and strike northeast, than in the south part, where the cross fractures are straighter and strike closer to east.

Paracale.—The halo of schistosity in the country rock around the granite mass finds its counterpart within the granite adjoining it, in a border zone of gneissic banding. Clear around the exposed border of the granite the gneissic banding, the contact and the schistosity in the halo form a series of parallel planes.

The gneissic banding owes its existence to the fact that tabular

minerals in the granite, notably biotite, are oriented around the borders of the mass in planes parallel to the contact. Flow lines, also, were noted in many places in the border zone of gneissic banding. Flow lines are recognized in parallel orientations of prismatic-tabular biotite or prismatic hornblende. Wherever mapped, flow lines lie in the plane of the nearest flow layers,[5] but although the flow layers reflect faithfully the attitude of that portion of the contact near which they lie, being nearly flat near the top of the mass and dipping steeply along its steep flanks, the flow lines seem to retain a N. 70° W. trend and gentle westward pitch, whether found beneath the flattish top or next the steep flanks. The flow lines are thus parallel to the axis of the "plunging anticline," *i.e.* to the major axis of the exposed portion of the granite mass.

The Paracale granite is considerably fractured. The dominant fractures strike east of north and dip steeply east, and are thus roughly perpendicular to the westward sloping roof of the granite "anticline." They are also perpendicular to the flow lines and flow planes wherever angular relations were measured. Further, their distribution appears to coincide more or less with that of the well developed primary flow structures, *i.e.* concentrated around the borders of the granite mass (Fig. 1*b*).

These fractures seem strictly confined to the granite. They are especially strong and persistent near the west end of the exposure, where erosion has only partly cut down to the roof, so that it seems they formed principally immediately below the roof. In the central part of the mass, where erosion has cut more deeply, such fractures appear nearly lacking, and confined largely to the neighborhood of the steep flanks (Fig. 1*b*).

Fractures of this dominant set appear again toward the east end of the granite exposure. If they are as closely related to the granite roof as seems likely, their appearance here may mean that the former position of the roof at the east end of the exposure lay not far above the present surface.

These Paracale fractures resemble in some respects the Hog Mountain cross fractures. They are perpendicular to the orig-

[5] Balk: *Op. cit.*, p. 23.

inal top of the granite intrusion. Those abutting against the steep north and south contacts in the central portion are roughly perpendicular to these contacts. They are, therefore, cross fractures, too, in a general way, in relation to the top and sides of an elongated tabular cake at the top of the granite. The bottom side of this cake is very ill-defined, but may be considered an irregular imaginary surface more or less parallel to the top, and limiting the fractures in depth, since the fractures show signs of dying out in depth at a fairly uniform distance below the top of the granite.

A further similarity exists in the fracture pattern of the two districts. Like the Hog Mountain cross fractures, the Paracale fractures carry acute-angle branches that die out not far from their parent fracture, or link two parent fractures that lie not far apart (Fig. 1*b*).

Mechanics of the Paracale and Hog Mountain Fracturing.

Paracale.—That the granite pushed its cover upwards is plainly shown by the attitude of the sediments. The beds dip steeply with the steep flanks of the granite mass, and assume their regional attitudes farther away from the contact. The intense schistosity around the granite mass bears witness also to the mechanical force of the intrusion.[6] The flow planes and flow lines inside the contact, and the planes of schistosity outside of it reflect the deformation produced. In terms of the deformation at any point near the contact, the maximum shortening took place in a direction perpendicular to the contact, to the flow planes within the granite, and to the schist planes in the adjoining country rock. Maximum elongation took place in a plane parallel to the flow layers, to the contact and to the schistosity; and the direction of the elongation within that plane coincides with that of the flow lines in the granite.[7]

The persistent N. 70° W. trend and gentle westward pitch of

[6] Balk: *Op. cit.*, p. 123.

[7] Balk, Robert: Structure elements of domes. A. A. P. G. Bull. 20: 54–55, 1936.

the flow lines indicate a decided lengthening of the granite mass, as it intruded, in the direction of the flow lines.[8]

The fractures in the Paracale granite described above are oriented perpendicular to the flow lines, and are evidently cross joints.[9] They fractured an elongated tabular mass of rock at the top of the granite and directly beneath its roof. They formed in a frozen cake at the top of an intrusive mass still molten, and elongating itself in the direction of the flow lines. By their formation the cross joints served to elongate the cake in the same direction.

Field observation proves that the cross joints formed after the walls of the intrusion had been rendered schistose. Soft schist lay above the cake when the cross joints formed, and the schist planes lay parallel to the top of the cake; uncongealed magma lay below the cake.

Balk[10] explains the mechanical origin of cross joints, and links them with tension joints in general, as follows:

> Experiments have been made by A. Föppl, E. Seidl and Hans Cloos. Tear cracks, or tension joints formed, if a block was squeezed so that its compressed surfaces were free to move at right angles to the direction of maximum compression. . . . The better the compressed block was lubricated . . . the better is the development of the tension joints. The more the compressed block and its surrounding soft material differ in brittleness, the sooner the cracks appear.
>
> These experiments show that if a brittle block, under compression, can yield sidewise, and its gliding friction is small, it will develop tear fractures in the direction of maximum compression.

These experiments duplicate the Paracale fracturing described. The brittle cake of frozen granite at the top of the magma was compressed by a shove from below in a direction perpendicular to its top and bottom sides. The flat platy "flow" structure beneath the roof of the granite may have been partly or wholly caused by a true flow of molten material; but that a strong upward shove of the granite mass took place is shown by the manner

[8] Balk, Robert: Structural behavior of igneous rocks. G. S. A. Mem. 5: 8, 1935.
[9] Balk: *Op. cit.*, p. 27.
[10] Balk: *Op. cit.*, p. 32.

in which the invaded strata have been domed and in places disrupted.

The compressed top and bottom surfaces of the brittle cake were free to glide in a direction perpendicular to that of the compression, for they were aligned with the N. 70° W. direction of extreme crustal yielding associated with the whole process of intrusion, and lying perpendicular to the vertical compression acting on the brittle cake. Further, the soft schist above the cake provided lubrication for movement in this direction with the schist planes oriented parallel to the top of the cake. The bottom surface of the cake was doubtless lubricated by the semi-liquid magma just below it.

The cross fractures appear, therefore, to be tension joints. Primary movement associated with such joints is in a direction normal to their walls. Fine-grained or porphyritic dikes, both acid and basic types, follow many of the cross joints. They may represent acid and basic expulsions from a magma undergoing differentiation and underlying the fractured cake. At any rate, they support the idea that the primary movement connected with the cross joints was normal to the joint walls. All other observed movements connected with these fractures took place after the dikes were intruded.

The later movements on the cross joints appear to be mainly fault movements, whereby the block on one side of a joint is displaced with respect to that on the other side. Most displacements are slight. The movements were probably related to a regional shearing stress that operated after consolidation of the granite and nearly or quite at the time of the mineralization.

Hog Mountain.—The diorite intrusion seems to contain some linear flow structures, although details are lacking. It notably lacks platy flow structures. This is to be expected where the walls of an intrusion are so soft that they are able to yield with the expanding magma.[11]

The diorite prismoid encased in soft schist and broken by cross fractures suggests at once the tension joint experiments and the Paracale cross joints. The Hog Mountain fracturing differs,

[11] Balk: *Op. cit.*, 80–83.

however, in some respects from that of the experiments and from that at Paracale. The fractured Hog Mountain prismoid is not straight, but warped. Cross fractures perpendicular to the major axis of the prismoid at the south end of the exposure (Fig. 1*a*) are therefore not parallel to cross fractures perpendicular to the major axis at the north end. In spite of this anomaly, let us assume that the Hog Mountain fractures are true tension joints formed parallel to the direction of a compressive stress, and perpendicular to the direction in which the compressed block was free to glide.[12a] The field facts may be examined to see whether the assumption is possible, and if so, what corollaries it carries with it.

The direction in which the supposedly compressed block was free to glide is defined in the assumption: it is perpendicular to the cross fractures and therefore coincides in direction with the major axis of the prismoid. The south portion of the exposure, where the major axis trends north-south and probably pitches gently south, and the cross fractures strike nearly east and dip north, will be dealt with first.

The direction in which the compressed block was free to glide has been fixed, as coincident with the major axis of this part of the prismoid. But the compressive stress might, theoretically, have acted along any line perpendicular to this axis, and contained in the plane of the cross fractures. What is the most likely direction in which the supposed compression acted?

Where a brittle block is compressed so that tension joints are formed, free lateral gliding of the sides against which the compression acts, is a *sine qua non* of the process. Clearly, of the three exposed sides of the Hog Mountain prismoid, the east and west sides could have glided most easily, for the soft graphitic schist planes lie in general parallel to those sides. Compression acting normal to the east and west sides would have had a direction trending east-west and inclined upwards to the east at about 25° from the horizontal. A direction normal to the east and west sides of the prismoid is normal to the planes of regional

[12a] Regional compression is assumed mainly for the sake of simplicity; a properly oriented regional shearing stress might have produced precisely the same deformation.

schistosity as well. If the diorite was intruded toward the close of the regional deformation that produced the schistosity it is a fair guess that the east-west compression, acting as just described, produced the schistosity, conditioned the elongation of the intruding diorite, and cross-fractured that mass after it had solidified.

The probability of this being the direction of compression derives added strength from another consideration: it is scarcely conceivable that an *external* force sufficient to crack the prismoid could have been transmitted far in any direction other than one about normal to the schist planes.

At Paracale, the stress that broke the brittle cake at the top of the granite was local, and was related directly to the process of intrusion of the granite mass. Why has an external force been assumed at Hog Mountain?

The fractured prismoid at Hog Mountain is not the top crust of a great intrusion. It is a comparatively small and narrow mass intruded more or less conformably along preëxisting schistosity; its under side rests on schist, and its only possible direct connection with a larger mass lies at depth and to the south, in the direction of pitch of the prismoid. It seems more likely that this small prismoid was fractured under stress from the outside rather than under internal stress connected with its own emplacement; and especially since a regional stress capable of fracturing the prismoid is known to have affected the area in which the prismoid lies at a time possibly not much earlier than the intrusion of the mass. It is true that a properly oriented compressive stress could have fractured the diorite at any time after that mass solidified. This follows because the passive setting conducive to such fracturing, *i.e.* the brittle diorite block and its soft enclosing schist, exists today. But regardless of when it might have acted, a compressive stress acting in the direction deduced for it above could have cross-fractured the south portion of the prismoid in the way it has actually been broken, and the cross fractures produced would be strictly analogous to those formed in the tension joint experiments.

If the presumed stress that fractured the south part of the pris-

moid was regional, how may one account for the fact that the cross fractures at the north end, where the prismoid is warped out of line, are themselves out of line with the east-west compressional stress? The situation suggests certain engineering compression tests, where, as shown by Griggs [12] compressed specimens fractured along anomalous directions that depended as much on the *shape* of the specimen tested as on the direction of the *stress* applied. The diorite prismoid is especially thin at its warped north end, and it may be that the tendency for it to break straight across overshadowed the tendency to break parallel to the direction of compression. The zigzag strike of some northeast cross fractures at the north end of the mass (Fig. 1*a*) suggests that they formed in response to two differing factors of formation.

Like the Paracale cross joints, the Hog Mountain cross fractures have been subjected to shearing movements; here, too, there are reasons for thinking that such movements might have taken place at about the time of mineralization. Lack of precise data makes the development of this idea by the writer too speculative an undertaking, but as a possibility it is touched on below.

Mineralization.

Paracale.—The cross joints in the granite have been mineralized, and form the principal gold-quartz veins of the district.

The ore mined to date probably averages better than 0.4 oz. gold per ton. The principal sulphides in their order of abundance are pyrite, the most abundant, followed by sphalerite, chalcopyrite and galena. The mineral assemblage is rather complex, and includes a number of minerals not recorded by the writer during his short stay in the district. The principal gangue mineral is quartz, greasy to vitreous in lustre, and varying in color from dark gray to glassy white. It appears to have undergone deposition throughout most of the period of mineralization, and where time relations are evident, the younger the quartz the glassier it appears to be. Commonly equigranular, the quartz

[12] Griggs, D. T.: The strain ellipsoid as a theory of rupture. *Am. Jour. Sci.*, XXX: 121–137, 1935.

shows marked variations in grain size in certain places. Drusy cavities are sparse, and delicate banding is lacking. Fragments of granite and of early quartz appear in the veins; they are set in a matrix of later vein-matter, and in places are rimmed by sulphides. Sheeting, generally parallel to the vein walls and developed in the vein itself and in the walls adjoining, is rather common; in more than one place late quartz carrying sulphides has been deposited along sheeting developed in earlier quartz. Such evidence lies behind the notion expressed above that shearing stresses were operative at the time of the mineralization; they seem to have brecciated and sheeted the veins as the latter were being formed.

Replacement of the granite was undoubtedly important in the formation of the Paracale veins; but the filling of openings, both in the granite and in early quartz, played a rôle as well. The mineral assemblage suggests " telescoping " by its complexity and the mixture of epithermal and mesothermal characteristics.

Secondary enrichment was unimportant in the formation of the gold ore bodies.

Hog Mountain.—The cross fractures have been mineralized and form the gold quartz veins of the district. The grade of ore mined runs about 0.2 oz. per ton in gold.

Pyrrhotite is the chief sulphide. Arsenopyrite, sphalerite and chalcopyrite are found in less amount; pyrite is rather scarce and galena is rare. The gold, finely divided, is in part intimately mixed with the sulphides.

The quartz was deposited more or less throughout the period of mineralization but changed gradually in type. The early quartz is dark gray, massive-looking with vitreous lustre, and contains myriads of vacuoles and inclusions. Successively younger phases of the quartz become correspondingly lighter in hue, fresher looking and freer of vacuoles and inclusions. The gray quartz, where undisturbed by mining operations and deep below the surface, is under inherited internal strain, for it shakes off such strain by snapping and cracking when exposed in stopes. This type shows strain shadows under cross nicols, whereas the

younger, light-colored quartz shows few.[13] The ore is brecciated in places; the earlier quartz was broken and the openings filled with sulphides and fresh quartz.[13] After the veins were at least partly formed they were subjected to shearing stress, for some exhibit prominent sheeting.

Such evidence suggests that tectonic stresses were operative at the time of mineralization, and acted on the veins while the latter were forming.

The Hog Mountain veins were formed by a combination of replacement of the diorite and filling of openings. Their mineral assemblage causes Park to place them in the hypothermal division of the genetic classification.

Secondary enrichment of the gold is held by Park to have been a negligible factor in the formation of the Hog Mountain ore bodies.

Ore Localization.

Paracale.—Ore localization in a regional sense was effected by the granite. Although spotty mineralization characterizes the entire district, major ore bodies are entirely confined to the cross joints within the granite mass.

Ore was localized in a minor way within these cross joints in places of pronounced changes in dip and strike; it is not difficult to connect such localization with the shearing stresses thought to have been operative during the mineralization, whereby through differential movement of vein walls past one another, segments suitably oriented became permeable to the mineralizing solutions, whereas others differently oriented became loci of shear (Fig. 2). Intra-mineral brecciation within the suitable segments probably acted to enrich these portions of the vein, since the gold in deposits of this type is apt to enter the veins late, and, in many cases, at precisely the right time to be deposited in openings formed in early barren vein matter. Ore controls originating in stresses active at the time of the mineralization may be called "dynamic." They are of supreme importance in more than one

[13] McCaskey, H. D.: Notes on some gold deposits in Alabama. U. S. G. S. Bull. 340: 36–52, 1908.

district, for instance, at Pachuca;[14] but at Paracale they are overshadowed by a control of a different nature.

The dominant control at Paracale was "static" rather than "dynamic," for it involved a passive feature of the setting in which the ore shoots formed, rather than active agents of movement and stress. The passive feature that governed localization of the Paracale ore shoots was the soft schist that capped the granite and against which the cross joints ended going upward. The major ore bodies in the cross joints formed directly beneath the capping. Each is a long and narrow shoot in the plane of its vein, and the major axis of the shoot follows the trace of the capping upon the vein, so that the inclination of the capping gives the pitch of the shoot. Beneath these long and shallow major shoots that hug the capping are lesser ones, equant or irregular in outline, and sporadically distributed. Precisely similar shoots are found in other veins in the granite from which the capping has been stripped, and which are now exposed by erosion in places well below their former tops. The deeper that exploration is conducted beneath the capping or its former position, the poorer the chances are for ore.

Concentration of ore minerals within a suitable receptacle rock and directly beneath an impervious capping has been noted in isolated instances by a number of observers. It has remained for Schuette[15] to develop the idea of trapping action as a general theory to explain the primary concentration of quicksilver in commercial ore bodies. The writer believes that trapping of solutions is a dominant factor in the concentration of ore minerals by no means limited to cinnabar, and that this fact has been little noted because the mode of trapping is often far from evident.

Trapping is strikingly evident at Paracale; and its effect on the primary concentration of gold in the veins below the capping can be precisely evaluated by comparing those veins with minor veins outside of the granite, where no schist trap existed.

[14] Wisser, Edward: Formation of the north-south fractures of the Real del Monte Area, Pachuca silver district, Mexico. A. I. M. E. Trans. 126: 442–486, 1937.

[15] Schuette, C. N.: Occurrence of quicksilver orebodies. A. I. M. E. Trans. 96: 403–486, 1931.

Ore in the veins within the granite was localized by the schist trap in a manner visible in section, not in plan; the solutions rising up the steep cross joints were impounded against the nearly horizontal dam of impermeable schist and dropped their load adjacent to the dam. Since the dam faced the rising solutions squarely across their path, continued influx brought more and more valuable material straight to the place where it was forced to deposit, and the trap was so perfect that no escape of the valuable material was possible.

The minor veins outside of the granite carry small irregular ore shoots, so widely scattered laterally and vertically that the cost of finding them exceeds the profit derived from mining them. The minor "dynamic" controls described as affecting minor ore localization in the veins within the granite seem to have been the sole controls in the veins outside. Such controls, manifest today by a preference of the small ore shoots for vein segments having a certain favorable strike (Fig. 2), involved little trapping action calculated to concentrate ore into large bodies. Ore-bearing segments on these veins alternate with barren segments of different strike, so that the veins show a "zigzag" ore control in plan, but not in section. This means that the crenulations in the vein-fracture surfaces are arranged vertically, like the folds in a curtain. Horizontal differential movement of the walls of such a crenulated vein-fracture results in openings elongated vertically, parallel to the crenulations, and separated one from the next by a closed and barren segment of the vein. Since the mineralizing solutions probably rose steeply, the openings produced by the dynamic ore control just described served more as channels promoting the rise of solutions than as traps opposing it. Lack of mathematical regularity in the crenulations limits, of course, the size of these openings, and all eventually close, or partly close, going up. It is under such pinchings in the openings that the small ore bodies appear to have formed, but conditions in these vein-fractures generally promoted dissemination rather than concentration of ore minerals.

So much for the structural testimony of vein genesis. There

follows the physico-chemical evidence of mineral assemblage and texture.

The presence of "telescoped" deposits beneath a trap, wherein low- and intermediate-temperature minerals are jumbled up and deposited together, suggests that the trap forced minerals that naturally would have become deposited above it, to be deposited beneath it at a horizon in the crust abnormally deep for them. A naturally great vertical range of deposition was telescoped into an exceedingly narrow one. The fact is of importance from the standpoint of the searcher for ore not only because the trapping concentrated rich bodies of gold ore. The abnormal depth at which much or all of the gold in these veins was deposited preserved most of the gold for the miner, since erosion failed to cut below the trap at the west end of the granite exposure, and apparently has not cut far below the former position of the trap at the east end. Had there been no trap, the gold would probably have been deposited in small shoots over a wide vertical range, and most of it would have long since been removed by erosion.

The veins outside of the granite are exposed at about the same elevations with respect to sea level as those within it. But they show a simple, rather deep-seated type of mineral assemblage and texture, and the small ore shoots suggest a horizon associated with the "roots" of ore. The lack of telescoping suggests that the solutions in the area of these veins would lose their gold mainly at horizons far above the present surface. If so, most of the ore shoots have been removed by erosion.

The evidence on vein genesis derived from physical chemistry is found therefore to harmonize with that from structure.

Hog Mountain.—According to Park [1] ore in the Hog Mountain veins is localized, apparently in a minor way, at sharp changes in the dip and strike of the veins, and at intersections with "shear zones." "Dynamic" ore control is suggested, but the failure of such control to account for the bulk of the ore suggests that some other and dominant control exists. Figure 4 of Park's paper is a longitudinal vertical projection of the Blue vein. Directly below the present surface, a major ore shoot, of considerable length

and shallow depth, extends clear across the diorite prismoid, from schist contact to schist contact. Since secondary enrichment of the gold appears to have been negligible, the shoot in question may be presumed to show faithfully the original form of that part of it not removed by erosion. Below the flat bottom of this major shoot are two smaller ore bodies, roughly equant in shape on the projection. The projection resembles exactly that of a typical Paracale vein within the granite, in an area where the schist trap has been stripped away, but where erosion has penetrated only shortly below the original horizon of the trap. The inference is that the major ore control at Hog Mountain was exerted by a capping of impermeable Wedowee schist that terminated the cross fractures going upward.

Whether telescoping of vein minerals took place at Hog Mountain as it did at Paracale is not known. Concentration of gold beneath a possible trap was probably less at Hog Mountain than at Paracale, for the grade of ore there is lower. The absence of galena, also, and other minerals of the intermediate depth zones suggests a comparative absence of telescoping at Hog Mountain. The reasons behind this may lie in original differences in composition of the ore solutions in the two camps, or in other factors.

CROSS JOINTS AND HINDERED FAULT MOVEMENTS.

This correlation study of the Hog Mountain and Paracale districts has dealt mainly with an analysis of conditions attending the formation of the cross fractures or tension joints in those camps. Since these fractures may have formed long before the time of mineralization at either camp, their mode of formation may seem extraneous to the search for ore.

Tension joints in general, however, and especially primary cross joints connected with intrusion, are promising places in which to look for ore, for the following reasons.

The critical period for many mining districts begins with intrusion and diastrophism and ends with mineralization. Cross joints are generally among the first fractures to form among those

connected with intrusion. They may be confined to the top of an intrusive mass or widely distributed over a broad segment of the crust arched by vertical compressive stress. Cross joints, coming so early in the cycle are, therefore, generally pre-mineral. Since they are tear, not shear fractures, they may not be straight. Since the initial ground movement connected with them was normal to their walls, they seldom carry gouge unless subjected to later shearing movements in the plane of their walls.

The early stages of intrusion and diastrophism are apt to be characterized by simple, widely distributed stresses few in number. This is especially true where the intruded region was physically homogeneous at the start of the cycle.

As intrusion increases in extent and complexity, the stresses in the intruded segment of the crust become correspondingly more complex. This is caused in part by the fact that the loci for intrusion multiply. Each new intrusion superimposes new local stresses upon the older regional stresses, and the new stresses act in their own distinctive directions. Complexity of stress is increased also by the fact that intrusions as they solidify may become massive buttresses. The region becomes increasingly heterogeneous structurally. Simple regional stresses reacting against such buttresses are disintegrated into complicated sets of shearing couples.

Fractures formed by the early, simple stress, such as regional cross joints, although formed originally as tension joints, are likely to be utilized by the later complex stresses as planes of shear. Compressive stress acting obliquely on such preëxisting fractures will induce some shearing movement on them; rotational stress, characteristic of the later period, may cause extensive shearing movement on properly oriented preëxisting breaks.

Movement under such conditions is likely, however, to be *hindered* rather than *free*. It has been noted that cross joints are apt to be crooked, and that they carry initially no gouge. They are poorly lubricated, therefore, to aid movement in the plane of their walls. They are also apt to hinder such movement for another reason: they are poorly oriented for the requirements of the stress inducing the movement.

A body deformed by stress changes shape in such a manner as to reach a position of equilibrium wherein the stress shall vanish and deformation cease. Under proper conditions the deformed mass will fracture, and change its shape through fault movements along the fracture planes. The mass will utilize preëxisting fractures for such movements when it is easier to do so than to set up new fractures or deform by flow. But unless the preëxisting breaks happen to coincide in attitude precisely with those that would have been set up had no such breaks been there, the tendency for fault movements along them will be hindered.

Hindered fault movements are connected in a most important manner with the localization of ore. Completely free movement of one fault block past another involves no strain in the parts of the block adjoining the fault. The case is that of one brick shoved past an adjoining brick on a table, with no pressing of the bricks together as they slide. But if high friction opposes the movement, a given force will displace one block with respect to the other less than with free movement. The parts of the blocks next to the fault will be intensely strained in the effort of the force to overcome the high friction opposing the movement. A shearing stress is set up, and the rock on both sides of the fault is stretched in a direction crossing the fault obliquely, and slanting toward the direction of movement (Fig. 2). If this tensional stress exceeds the tensional breaking strength of the deformed rock, "feather joints" or tension fissures form perpendicular to the direction of stretching.

Feather joints forming not long before, or during, the period of metallization are likely to make important veins. The great Balatoc veins at Baguio are feather joint branches of barren shear faults; hindered movement on these faults produced the feather joints. In the Paracale granite, the late fault movements on the cross joints were hindered because the joints originally carried no gouge, because they are crooked in detail, and because they were improperly oriented to suit the shearing stress believed to have induced the movements. Feather joints formed. Since the stress that induced them was closely connected in time with the mineralization, the feather joints became loci for ore.

The " shear zones " at Hog Mountain may have originated as feather joints. If they did, the cross fractures with which the feather joints are associated were subjected to shear when the feather joints were formed, and movement on the cross fractures

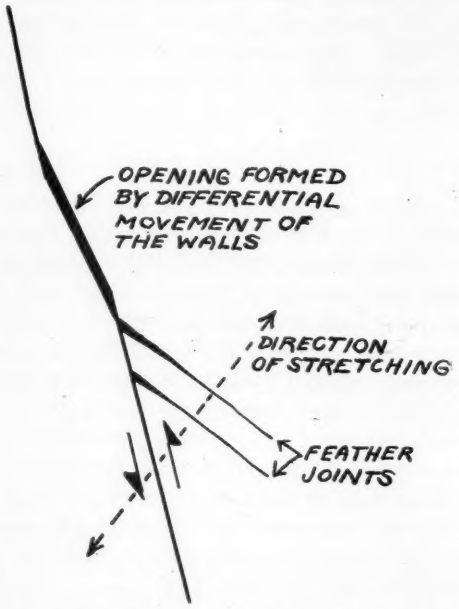

FIG. 2. Plan showing effects of hindered movement on a crooked fault.

was hindered, for the same reasons, probably, that similar movement was hindered on the Paracale cross joints. Observation shows that the " shear zones " in their turn became seats of shearing movements, probably under increasingly complicated conditions of stress. That the change in character of the " shear zones " from that of gaping feather joints to tight shear planes took place before the mineralization is suggested by the fact that they carry practically no ore. That shearing movements occurred on the shear planes at the precise time of the metallization

is indicated by the fact that "shear zones" localize ore in the veins that they cross and slightly displace.

Cross joints are promising localities for ore not only because late movement on them was apt to be hindered and gaping feather joints likely to form. Cross joints may carry ore themselves as well as in their feather joint branches, because they tend to be crooked in detail. Differential movement of the walls of a "zig-zag" fracture may form openings suitable for the deposition of ore (Fig. 2).

TIME RELATIONS OF STRESS AND METALLIZATION.

Cross joints are commonly filled with dikes that were intruded as the joints were formed, or as the joints gaped open under continuation of the same stress that formed them. Whether a joint will become a locus for later movements in the plane of its walls may depend on the nature of the dike it carries, combined with that of the country rock in which joint and dike occur. Cross joints in extrusive rocks and filled with dikes of a physical character practically identical with that of their walls seldom suffer late shearing movements. Welded by the dikes to their walls, they become integral portions of the country rock. Cross joints filled with fine-grained or porphyritic dikes but forming in coarse, holocrystalline rock, are commonly seats of late movement. Since the dike contacts separate rock units differing widely in their physical characteristics, they are likely to be planes of notable structural weakness. Cross joints in granitic rock are, therefore, more likely to carry ore than those in fine-grained rock, for most dikes are fine-grained and tend to "freeze" to fine-grained walls.

The time relation of the late movements discussed above with respect to the metallization is a critical factor in ore control. Openings formed long before the time of metallization may be closed before that time by gravitational or other stress. But the sequence of events in the cycle of intrusion, diastrophism and mineralization that characterizes the critical period for most mining districts offers a fair possibility that the openings described may form at a time closely linked with that of the metallization.

It has been noted that the complicated stresses that produce such openings mostly operate toward the close of the cycle. Since the mineralization is also one of the closing events of the cycle, the waning phases of diastrophism represented by the fault movements that make the openings may persist into the period of metallization. That they commonly do so is suggested by the increasing body of evidence to show that many veins were formed by "accretion," [16] that is, by the successive creation and immediate filling by vein matter of openings caused by faulting and shattering.

The details of "dynamic" ore control outlined above are clearer elsewhere than at Hog Mountain or Paracale, and ideas concerning such control were derived from other districts. The broad conception of the cycle of intrusion, diastrophism and mineralization, with diastrophism increasing in complexity as the time of mineralization approaches, came from study of districts more complex than Hog Mountain or Paracale. But ideas derived from detailed work in well-studied "control" districts may be applied with confidence to camps less known. Here is a practical use for the critical comparison of mining districts on the basis of any shared features related to the localization of ore.

THE TRAPPING OF ORE SOLUTIONS.

In some districts, such as Pachuca,[17] dynamic ore controls appear of paramount importance. But the dominant control at Paracale, and possibly at Hog Mountain as well, was "static"; it was exerted by a schist trap. I have stated my belief that trapping action resulting in the concentration of metallic minerals to form ore bodies is commoner than generally realized, and has been little noted because it is generally not plainly shown. Simple pinching of vein fissures upward may form a trap, whatever the cause of the pinching. The pinching of fissures above ore may be seen in many districts. The great Dos Carlos vein at Pachuca

[16] Hulin, C. D.: Structural control of ore deposits. ECON. GEOL., 24: 23, 1929.

[17] Wisser, Edward: *Op cit.* Also, by the same writer: The environment of ore bodies. A. I. M. E. Tech. Pub. 1026: 1–84, 1939.

does not outcrop, nor does the Pinguico vein at Guanajuato. At Baguio, the large Balatoc veins outcrop as feeble quartz stringers or weak, narrow zones of barren fractures. Strong and productive veins that pinch upward are usually considered merely examples of the unpredictable vagaries of ore formation. The writer thinks that the reason such veins *were* productive may be because they *did* pinch upward.

In a mining district of high relief the veins are commonly exposed at greatly differing elevations above sea level. In general, where the veins of a district all pinch upward at roughly the same horizon above sea level, those exposed in the deep canyons outcrop as wide veins, but those found by mine workings under the ridges might not outcrop at all. This condition seems to prevail at Baguio. The Antamok vein, outcropping in a deep canyon, carries wide and productive quartz on the surface. The feeble outcrops of the Balatoc veins lie upon a high ridge many hundreds of feet vertically above the Antamok canyon. It seems likely that the Antamok vein, as well as those of Balatoc, originally pinched toward the surface.

CONCLUSIONS.

The possibility that most productive veins pinch upward, or end against a flat trap as at Paracale, is disturbing to the searcher for ore. If erosion had cut down at Paracale a few hundred feet less than it has, not a vein would have been found. Since one cannot afford to look below every flat-lying body of schist that might cap ore, or sink on every feeble vein outcrop that might represent a pinching above ore, one may fail to find many ore shoots that do exist below such features. The only possible tool to find such hidden ore shoots lies in conceptions of ore localization derived from the comparison and classification of mining districts from the standpoint of the localization of ore. Settings that appear from analogy to offer *a priori* chances for ore may be explored with reasonable hopes for success, by applying to them criteria of ore control derived from the painstaking study of "control" districts. Such criteria must never be purely empiri-

cal. The comparative study of mining districts from the standpoint of ore control must lead to the forming of laws for the localization of ore as time-tested as those for the physical chemistry of ore formation derived from the genetic classification.

ACKNOWLEDGMENTS.

The writer is indebted to a number of engineers and geologists in the Paracale district for information to supplement the meagre data he was able to collect himself. Among these helpful friends may be mentioned particularly Mr. D. L. Gardner, Geologist, San Mauricio Mining Co.; Mr. J. E. Fyfe, Chief Engineer, United Paracale Mining Co.; and Mr. D. C. Gregg, Geologist, Mining and Development Co. of the Philippines. The courtesy of Mr. C. F. Park, Jr., United States Geological Survey, and of the American Institute of Mining and Metallurgical Engineers in permitting reproduction of the geologic plan of Hog Mountain is also appreciated.

SAN FRANCISCO, CALIF.,
March 1, 1939.

SIENNA ("OCHER") DEPOSITS OF THE CARTERSVILLE DISTRICT, GEORGIA.[1]

THOMAS L. KESLER.

ABSTRACT.

Sienna ("ocher") deposits in the Cartersville district, Georgia, occur in the contact zone between dolomitic limestone and underlying quartzite of Lower Cambrian age. These rocks, together with interbedded schists, were folded and recrystallized probably near the close of Paleozoic time. Simple fissures and transverse and oblique faults, formed during the late stages of folding, admitted hydrothermal solutions, which deposited concentrated masses of hematite and pyrite, and other ore minerals, in the dolomites and calcareous schists. There is some evidence that large bodies of iron carbonate also were deposited.

Subsequent weathering has removed the dolomite near the surface, and its residuum in many places rests upon the more resistant quartzite. Iron derived from the hematite and pyrite, and possibly from iron carbonate, was transferred by meteoric waters and deposited as hydrous oxides by partial replacement of (1) irregular, structureless bodies of the residuum, and (2) irregular areas in schists both at the base of the dolomite and beneath the uppermost quartzite bed. A relatively thin superficial portion of the uppermost quartzite bed also was replaced. Transfer of the iron has taken place over short distances only, and the present positions of the sienna deposits reflect essentially the positions of the deposits of source minerals.

CONTENTS.

Introduction 325
Production 325
Geologic association of the deposits 326
  Associated country rocks 326
  Structure 330
  Hydrothermal minerals 333
Oxidation and weathering 337
Sienna deposits 338
  Occurrence 338
  Origin 339
Effect of geologic conditions on mining 341

[1] Published by permission of the Director, Geological Survey, United States Department of the Interior. Presented before the Society of Economic Geologists, Knoxville, Tenn., Meeting, October 6, 1938.

INTRODUCTION.

THE Cartersville mining district is located in eastern Bartow County, Georgia, approximately 35 miles northwest of Atlanta. The town of Cartersville is the commercial center of the district, and is situated on the western margin of an elongate area that contains deposits of barite, manganese, hematite, brown iron ore, and "ocher" or sienna. This area trends generally northeast, is 18 miles in length, and has a mean width of about two miles. It coincides approximately with a series of ridges that separates the Appalachian Valley and Ridge province on the west from the Piedmont province on the east. The United States Geological Survey is now completing a study of the stratigraphy, structure, and mineral deposits of the district, and the material contained in this paper is drawn largely from the unfinished work. The friendly cooperation of the mine owners and operators has greatly aided the investigation.

The deposits listed above are notable for their close association, although other metallic and nonmetallic minerals occur in the district. The first of the group to receive commercial attention was the brown ore which was mined at least as early as 1840. The production of manganese began in 1866, and that of "ocher" in 1877. It is believed that barite mining began about 1887.

A detailed study[2] of the properties of iron-oxide mineral pigments in this country has been made recently by the United States Bureau of Mines. As a result of this work, the orange-yellow Cartersville pigments have been classed as siennas rather than ochers; accordingly, the term sienna in this paper is synonymous with the term ocher as employed by previous writers.

PRODUCTION.

Figures showing quantity and value of "ocher" produced in Georgia were published from 1889 to 1914.[3] During this period

[2] Wilson, Hewitt, and others: Iron oxide mineral pigments of the United States. U. S. Bur. Mines Bull. 370, 198 pp., 1933.

[3] Mineral paints, in Mineral Resources of the United States, U. S. Geol. Survey, periods 1889–1893 and 1900–1914. Mineral paints, in Annual Reports of the U. S. Geol. Survey, period 1894–1899.

121,043 tons valued at $1,286,630 were sold, and annual outputs ranged from 600 to 11,420 tons. Most if not all of the total output is attributed to the Cartersville district, as there has been no other producing area of importance in the State. Almost no information is available for earlier and later years. Santmyers [4] reports an approximate production of 15,000 tons from the district in 1929. The writer is informed by one of the operators that the total output for the district reached a peak in or shortly after 1930, when it was about 20,000 tons. It has fallen steadily since then largely as a result of decline in its use as a filler in the manufacture of linoleum. There is some interest, at the present time, in the potential use of Cartersville sienna in high-iron cements.

Tailings left from the washing of brown iron ore and hematite in early operations contain some sienna, and minor but rather constant amounts are lost at the present time in the washing of barite. There is no record of any attempt to save this sienna as a by-product, and the present condition of the market is not likely to stimulate such an effort.

GEOLOGIC ASSOCIATION OF THE DEPOSITS.

Associated Country Rocks.

Locations of the principal sienna mines and their areal geologic relations are shown in Fig. 1. The deposits are associated exclusively with metamorphosed dolomitic limestone, shale, and sandstone of Lower Cambrian age. Hayes [5] termed the dolomitic limestone Beaver, and a part of the quartzite Weisner, recognizing the occurrence of shales in each; however, the name Beaver was later abandoned in favor of Shady, partly because of the apparent equivalence of the formation with the Shady dolomite of Tennessee. Fossils typical of the Shady fauna [6] have been

[4] Santmyers, R. M.: Ocher and ochery earths. U. S. Bur. Mines Inf. Circ. 6132, p. 8, 1929.

[5] Hayes, C. W.: Geologic relations of the iron ores in the Cartersville district, Georgia. Am. Inst. Min. Eng. Trans., vol. 30, pp. 404–406, 1901.

[6] Identifications by Charles E. Resser of the Smithsonian Institution.

found at 19 localities in the western portion of the area shown in Fig. 1. Gneisses and schists having a wide range in mineralogic composition lie to the east and southeast of the mining district, but further consideration of them is not essential to this paper.

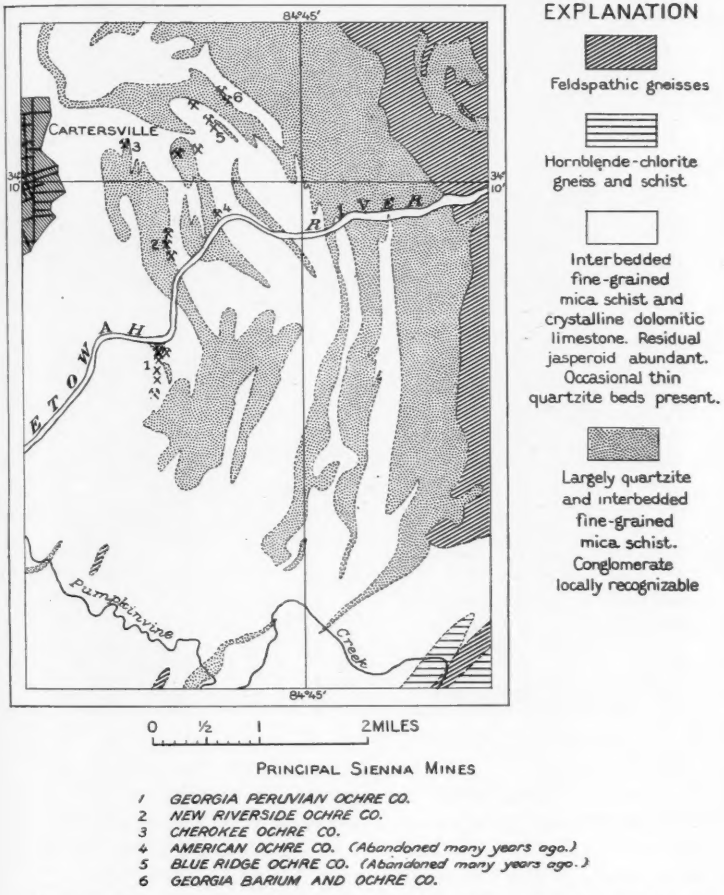
84°45'
CARTERSVILLE
34° 10'
R I V E R
E T O W A H
Pumpkinvine
Creek
84°45'
0 ½ 1 2 MILES
EXPLANATION
Feldspathic gneisses
Hornblende-chlorite gneiss and schist
Interbedded fine-grained mica schist and crystalline dolomitic limestone. Residual jasperoid abundant. Occasional thin quartzite beds present.
Largely quartzite and interbedded fine-grained mica schist. Conglomerate locally recognizable
PRINCIPAL SIENNA MINES
1 GEORGIA PERUVIAN OCHRE CO.
2 NEW RIVERSIDE OCHRE CO.
3 CHEROKEE OCHRE CO.
4 AMERICAN OCHRE CO. (Abandoned many years ago.)
5 BLUE RIDGE OCHRE CO. (Abandoned many years ago.)
6 GEORGIA BARIUM AND OCHRE CO.

FIG. 1. Generalized outline map showing distribution of major rock types in the southern part of the Cartersville district.

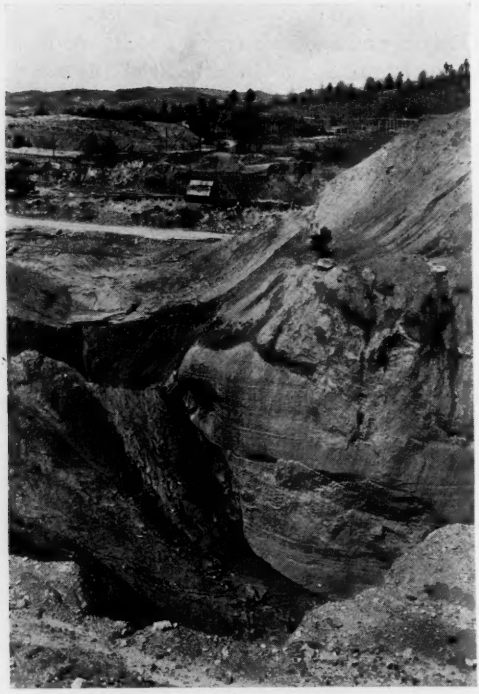

FIG. 2. Large pinnacle of the Shady dolomitic limestone, exposed in barite mining. The nearly horizontal bedding is shown clearly by micaceous laminae that represent original thin shale beds.

The Cambrian rocks with which the deposits are associated were folded and converted to low-grade metamorphic rocks during the Appalachian orogeny near the end of Paleozoic time. The effects of metamorphism are shown most clearly in rocks that were originally argillaceous. These rocks, whether associated with limestone or with quartzite, have been recrystallized into fine-grained muscovite schists whose foliation almost without exception coincides with bedding. These features are well defined, not only in the thicker, non-calcareous beds, but even in the thin

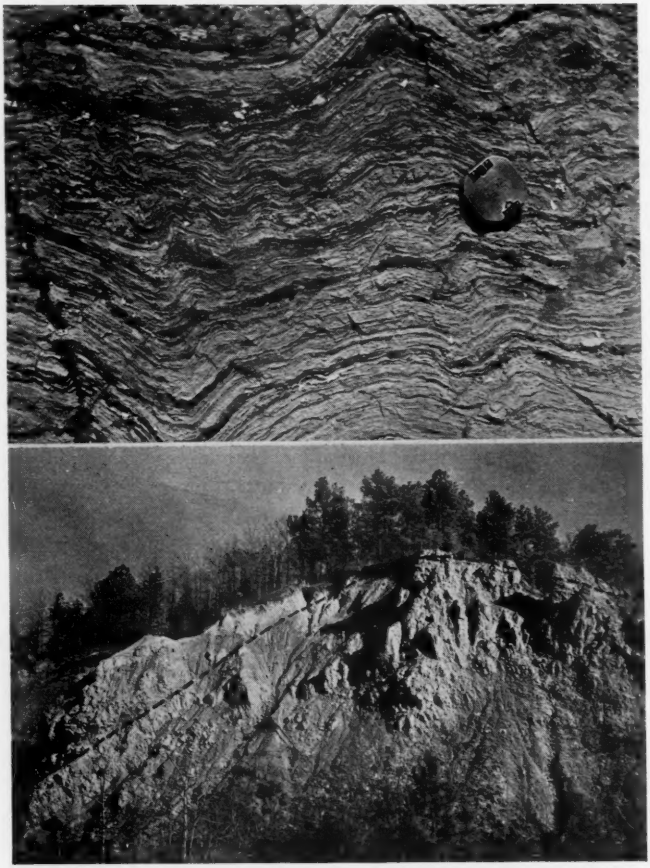

FIG. 3 (upper). Recrystallized shale showing nearly maximum distortion of the well-preserved bedding. The darker beds contain finely-disseminated graphite. Exposure 1.5 miles east-northeast of Cartersville.

FIG. 4 (lower).. Open anticline in fissured quartzite overlain by dolomite residuum containing sienna and much jasperoid. The dash line shows approximately the original contact, now greatly obscured by weathering.

layers and partings that separate dolomitic limestone beds (Fig. 2). Graphite is a common constituent, particularly in non-calcareous schists. It is locally confined to specific beds (Fig. 3), and is of no stratigraphic significance. Surface waters have penetrated the schists deeply, and oxidation and leaching have given them a wide variety of colors.

The quartzite associated with the mineral deposits is dark bluish gray where fresh, but becomes light gray to nearly white under the influence of weathering. Beds range in thickness from less than an inch to several feet, and are interbedded with schists, apparently without any regular stratigraphic succession in different parts of the district. Thin sections of the typical vitreous, fine-grained rock show no original sand grains. The rock contains minor but rather constant amounts of muscovite, and in places massive quartzite beds appear to grade into mica schist, reflecting original lithologic change. Microscopic zircon, biotite, and tourmaline are present in minute amounts.

The carbonate rock of the district is almost entirely dolomitic, published analyses showing an average of 29.22 per cent CaO and 19.62 per cent MgO. Field tests with acid rarely showed effervescence of the unpowdered rock, and therefore it is called dolomite in this paper. It ranges in color from light dove gray to dark blue gray, and is finely crystalline. Intergradation of dolomite and schist is a striking feature. The distribution of these intimately related rocks is shown in Fig. 1, and is considerably more extensive than was recognized by Hayes. In the area shown in Fig. 1, dolomite is dominant over schist in the general vicinity of mine number 1 southeast of Cartersville. North and south of this region, schist gradually predominates, and dolomite members become thinner and of less persistence. Careful tracing has proved the continuity of this sequence of dolomite and schist in spite of marked variations in their relative abundance.

Structure.

Broadly, the dolomite-schist formation appears to overlie the quartzite-schist formation, but beds in the transition zone between

the two are not of the same thickness or succession in all exposures. Typical differences are exposed in the workings of two of the mines shown in Fig. 1. In and beneath an open cut at mine number 1, there appears to be an uninterrupted thickness of the quartzite in excess of 45 feet (Fig. 4). This quartzite is overlain directly by fossiliferous Shady residuum from which sienna has been mined, both here and elsewhere on the property. The same general stratigraphic relationship is exposed in the south open cuts of mine number 2, except that here the original shaly character of the basal dolomite is evident in the thinly stratified siennas, umbers, and soft manganese dioxide in the floor of the cut. A quarter of a mile to the north, on the same property, a more recent cut (Fig. 5) has revealed the uppermost quartzite bed to be approximately 18 inches thick, overlain by dolomite residuum, and separated from similar underlying quartzite by about 10 feet of thin-bedded quartzite and schist. Portions of the schist have been replaced to different degrees by hydrous iron oxide.

Quartzite, because of its resistance to erosion, is the most reliable indicator of geologic structure in the district. It shows that the rocks of the western part of the area shown in Fig. 1 are characterized by open folds that die out eastward within short distances and grade into isoclinal folds overturned to the west. Dips to the west and to the east commonly range between 30 and 60 degrees.

Two forms of rupture have been observed in the quartzite. The simplest form is exposed in the Georgia Peruvian Ochre cut (mine no. 1) on the Etowah River. The cut (Fig. 4) exposes quartzite in an anticline, overlain by dolomite residuum. The upper bed is massive, and is transected by tension fissures that extend ten feet or more downward from the top. The walls of some stand nearly a foot apart, although weathering probably has had some effect in widening them. Strike joints are common below the uppermost beds. It appears obvious that fissures must have been formed in the overlying dolomite as well.

The other form of rupture comprises transverse and oblique

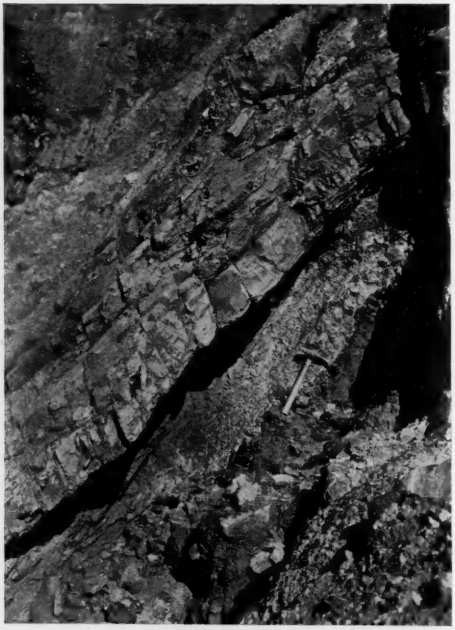

FIG. 5. Upper quartzite bed 18 inches thick, overlain by dolomite residuum that contains barite, and underlain by schist differentially replaced by ferric hydroxide. The dark layer just below the hammer is low-grade sienna.

faults, some of which show measurable offsets. One of these, with an offset of 50 feet or more, is exposed in the older south workings of the New Riverside Ochre Company. Sienna and barite have been mined on both sides of this fault. In this connection, the writer has found that numerous mineral deposits throughout the district occur where oblique and transverse faults intersect contacts between dolomite and quartzite, and that appreciable although not necessarily commercial quantities of sienna are present in most of these deposits.

Hydrothermal Minerals.

After recrystallization of the Cambrian rocks, and after most of the regional deformation had occurred, hydrothermal solutions formed mineral deposits throughout the district. Channels of three types permitted the solutions to permeate the country rocks. Two of these, fissuring and oblique faulting incident to folding of the rocks, have been mentioned above. The third and most general type comprised the foliation planes of the schists, along which solutions could travel slowly but with much greater ease than through quartzite or dolomite. Field evidence indicates that solutions passed most readily along the faults, for the greatest concentrations of ore minerals occur adjacent to them, but the channels of all three types probably formed a vast connected system.

The hydrothermal minerals and associations of particular interest in relation to the sienna deposits are described below in their probable genetic order:

Pegmatite.—The writer has discovered pegmatitic veins of quartz and potash feldspar at 13 places in rocks included by Hayes in his Weisner, Beaver (Shady), Rome, and Conasauga formations. Most of these veins were found in areas of relatively poor outcrops, and it is reasonable to assume that they represent only a small percentage of the total number that are present. The pegmatites range from a fraction of an inch to nearly a foot in thickness, and from a few inches to more than 20 feet in length. They lie both parallel to and across the bedding, and are physically isolated from any igneous rock; hence it appears that they have not been injected or intruded as magma, but have been deposited from magmatic solutions. Laminae of enclosing schists grade into the pegmatite, suggesting that the solutions gained access along foliation and fracture planes, and replaced the walls. The veins have produced no conspicuous mineralogic changes along their borders, and it is inferred that temperatures were too low to permit the formation of such minerals as wollastonite, diopside, hedenbergite, garnet, or amphibole through reaction between the silica of the pegmatite solutions and the dolomite and mica of the wall rocks.

No contact relations between the pegmatites and the hydrothermal minerals discussed below have been observed, but it is believed that the pegmatite solutions probably penetrated the rocks first. The introduction of the pegmatites and the ore minerals obviously took place since Lower Cambrian time, and after most of the general deformation had taken place. Therefore, if folding occurred during the Appalachian orogeny, mineralization probably accompanied or followed the final stages of the process. Several lines of evidence that will be presented in the complete report on the district indicate that the mineralizing solutions had their source to the east of the mining district, and were genetically associated with rocks that have been heretofore regarded as of pre-Cambrian age.

Specularite.—This mineral occurs in the lower portion of the dolomite-schist formation in schists and in siliceous beds that may be replaced dolomite. It is especially abundant as float in the vicinity of recognized faults and in localities where the rocks are known to be faulted or fractured, but where the breaks cannot be delineated because of inadequate exposures. The specularite has replaced schist, and preserved the finely micaceous texture of the rock as well as small folds and plications similar to those found commonly in unmineralized schists. No hydrothermal minerals have been found enclosed by or in contact with the hematite other than late quartz and fine grains of magnetite that seems to be nearly or entirely of contemporaneous origin. These facts, together with the generally accepted idea that hematite is deposited at temperatures higher than those that prevail during deposition of sulphides and barite, lead the writer to believe that specularite was one of the earliest hydrothermal minerals to form.

Carbonates.—Veins of coarsely crystalline carbonates are fairly common in the dolomite of the district. In some veins the carbonate is calcite and in others dolomite, but both are believed to have been derived from the carbonate wall rocks by solutions that traveled along fissures. The carbonates, with early vein quartz and a little pyrite, have filled these openings. From the manner in which some of the veins swell to dimensions greater than would

be expected of simple fissure deposits, it is evident that locally they have replaced the wall rock.

The variable composition of the carbonates in these veins suggests the possibility that ankerite and siderite also may have formed where original conditions provided iron as a constituent. McCallie [7] and Catlett [8] report the occurrence of iron carbonate immediately above quartzite at Sugar Hill, in the northern part of the district. It was exposed during early brown iron-ore mining, and the origin of the iron ore was attributed to the supergene alteration of this carbonate. It is possible that the carbonate itself is a product of weathering intermediate between leached pyrite and brown ore (see Lindgren [9] and Catlett [10]), but the fact that pyrite occurs in the carbonate,[11] together with the known mode of occurrence of the sulphide elsewhere in the district, indicates that both are hydrothermal products. The iron carbonate seen by McCallie and Catlett was undoubtedly in the Shady dolomite and schist, for McCallie [12] observed limestone in the valley of Little Pine Log Creek a short distance northeast of the mines, and the writer has traced the typical siliceous Shady residue around the north end of Little Pine Log Mountain to Sugar Hill.

Barite.—Barite occurs in composite crystalline form in highly fractured dolomite. It fills fissures in the same manner as the secondary carbonates, and also forms irregular bodies that probably were formed by replacement of the rock. Locally, in the uppermost zone of weathering above extensive occurrences of the hydrothermal mineral, clusters and individuals of beautiful clear crystalline barite have formed in openings by precipitation from supergene solutions.

Pyrite.—Pyrite is present throughout the district in dolomite, jasperoid, schist, and quartzite, but its distribution is uneven. It

[7] McCallie, S. W.: A preliminary report on a part of the iron ores of Georgia. Georgia Geol. Survey Bull. 10A, pp. 19, 162–163, 1900.

[8] Catlett, C.: Discussion of an earlier paper by H. M. Chance. Am. Inst. Min. Eng. Bi-monthly Bull. 24, pp. 1179–1183, 1908.

[9] Lindgren, W.: Mineral deposits, 4th ed., pp. 370–371, 1933.

[10] Catlett, C.: op. cit., p. 1182.

[11] Catlett, C.: op. cit., p. 1180.

[12] McCallie, S. W., op. cit., p. 157.

occurs rather consistently along boundaries between barite and dolomite, and is isolated within barite. Its occurrence in carbonate veins has been mentioned above. Considerable field evidence indicates that the principal lodes of pyrite were deposited in dolomite and dolomitic schist. The wide range in the occurrence of the mineral suggests that it was deposited continuously during all post-specularite mineralization. This appears likely in view of the extremely close genetic relationship between the other post-specularite minerals.

Galena and Sphalerite.—Microscopic galena and sphalerite were first identified by M. N. Short in barite collected by the writer at Iron Hill, 6 miles east-southeast of Cartersville. They were identified subsequently by the writer in barite from the property of the New Riverside Ochre Company. These sulphides are present in very small quantities, and no commercial deposits have been found. They are mostly accompanied by somewhat larger amounts of pyrite.

Jasperoid.—The final stage of hydrothermal mineralization included the introduction of much quartz. The results of silicification are most pronounced in the dolomites that have been replaced by large masses of jasperoid. The fresh rock is dark gray and fine-grained, and it has a dull appearance in contrast to the vitreous luster of fresh quartzite.

Of the few exposures of jasperoid in place, the most conspicuous is on the ridge west of the Paga barite mines, where the quartz has replaced a bed of dolomite about 6 feet thick. The weathered silicified bed stands out prominently, and dips steeply to the west. Elsewhere in the district residual boulders 20 feet or more in diameter are known, and the abundance of jasperoid boulders in the adjacent areas indicates that weathering has separated them from irregular jasperoid masses of great extent and thickness. Silicification of the dolomite progressed along and from fault zones and fractures where it now preserves the characteristic cleavage of coarse vein carbonates, and encloses angular masses of barite and early quartz, all of which were deposited previously in these same fractured zones. Undistorted bedding

planes of thin-bedded dolomites are well preserved in some places, indicating that they may have served as channels for the introduction of silica. Even where silicification is least conspicuous the dolomite commonly is cut by veinlets from which quartz has tended to penetrate and replace the adjoining rock.

Entire hills and ridges are covered and underlain by jasperoid. Much of it has been mapped and described as quartzite by earlier workers, although in places it contains fossils that occur characteristically only in limestone or dolomite of the Shady formation. They have been found at several places in rock mined from the thinner-bedded silicified dolomites. The fossils are found also in jasperoid boulders that show no preserved rock structures. These probably represent original organic reefs.

OXIDATION AND WEATHERING.

The dolomite-schist formation has been eroded more readily than the underlying quartzite that crops out on the crests and slopes of ridges. Down dip, the quartzite passes beneath a gradually thickening residual mantle left from the weathering of the overlying beds. Near the base of such a slope, the residuum may be 100 feet or more thick. Mining operations have exposed remnants and pinnacles of dolomite in several localities.

The residuum of the dolomite and schist consists of white, yellow, red, and brown clay containing fine grains of muscovite and quartz and boulders of jasperoid. The bedding of calcareous schists is preserved where slumping has not destroyed it. Iron oxides are generally present in quantities sufficient to color the clay, but locally they occur in concentrations that form commercial bodies of sienna and brown ore. Manganese oxides and barite also occur in the residuum, and, like the larger deposits of sienna and brown ore, are rather definitely localized.

The literature indicates that much of the earlier confusion between quartzite and jasperoid was based on cursory examination of open-cut mines where the residuum generally contains boulders of each. The quartzite boulders are float from upslope, whereas the jasperoid boulders, freed from the dolomite, are more nearly

in place. Therefore, the quartzite boulders occur most commonly on or close to the surface and in the upslope portions of ore-bearing residual material. In contrast, the jasperoid is more abundant and occurs through the entire residuum, though not with even distribution. Normally the quartzite boulders are whiter and coarser-grained than those of jasperoid, which are stained characteristically yellow throughout by ferric hydroxide, the surfaces sometimes altering in color to dull dark red. The jasperoid disintegrates more rapidly than quartzite, weathering to very fine sand. Occasional small weathered boulders that are pure white and crumble to a silica so fine that it resembles polishing powder indicate that iron oxides have not penetrated all of the jasperoid.

SIENNA DEPOSITS.

Occurrence.

Most of the sienna deposits occur in residuum that overlies quartzite, although this order apparently is reversed in two or three places owing to the stratigraphic variability of the contact zone. Examination of the literature indicates that only LaForge[13] recognized and briefly mentioned the more characteristic relationship. Workings in such localities show the sienna to occur on or near ruptured quartzite, and principally in two ways: (1) as irregular, structureless bodies in the basal dolomite residuum, and to a minor extent in the uppermost quartzite bed; and (2) as laminated bodies lying above or beneath the uppermost quartzite bed. Barite, and umber, a dark manganiferous equivalent of sienna, are found commonly in the same residual bodies with sienna. Much smaller quantaties of brown iron ore and specular hematite also occur as loose fragments. Conversely, all iron ore workings contain small to moderate amounts of sienna.

Deposits of both types have indefinite boundaries characterized only by a gradual diminishing of iron-oxide content as they grade into adjoining material. The lack of lamination in deposits of

[13] Hull, J. P. D., LaForge, L., and Crane, W. R.: Manganese deposits of Georgia. Georgia Geol. Survey Bull. 35, p. 64, 1919.

the first type makes their attitudes as indefinite as their boundaries. The adjoining material is principally slumped residuum which is either lean or barren and also without structure; hence, any form or attitude that such a deposit may possess is limited only by the boundaries of the residual mass in which it occurs. It may be merely a pocket measurable in inches, or, as is more common, a sinuous body ("vein") several feet in any dimension.

In contrast, deposits of the second type have definite attitudes, and their major dimensions are along the bedding, which is preserved in the sienna. Schists, perhaps originally calcareous, have been most extensively replaced by the hydrous oxides. The uppermost quartzite bed generally has been permeated to depths ranging from a few inches to 10 feet, but the intensity of permeation everywhere diminishes from top to bottom, and this zone of replacement has produced comparatively little sienna. Although the grade of sienna in these laminated deposits varies, single bodies attain strike and dip lengths of several hundred feet, and thicknesses ranging from a few inches to more than 25 feet.

Origin.

The rigid association between sienna and the common products of oxidation and weathering indicates that the deposits have been formed by meteoric agencies. Hydrous iron oxide has not been found in any fresh rock, but has replaced weathered bedrock and its residuum indiscriminately. Thin films of the hydroxide have been observed coating weathered surfaces of specularite and brown ore.

Of the hydrothermal minerals already described, specularite and pyrite unquestionably have served as the principal if not the only sources of the iron oxides in the deposits. Sienna is found without exception where appreciable quantities of these minerals are still present. McCallie [14] records the occurrence of pyrite at four of the brown iron-ore mines in the district, and the writer has noted the derivation of brown ore from pyritic lodes at three other localities in addition to one of those mentioned by McCallie.

[14] McCallie, S. W., op. cit., pp. 144, 154–155, 163, 165.

The reported extensive occurrence of iron carbonate at Sugar Hill suggests that it also may have been present generally in the district, although deep weathering has removed it from exposures.

Quartzite beds obstruct downward seepage throughout much of the district, and sienna deposits occur only where such beds are overlain by crystalline dolomitic limestone and schist, or their weathered residual matter. Consequently, the source minerals of the ferric hydroxide must have been present in the dolomite or its interbedded schists, or in both. If these rocks, however, had contained the source minerals in even distribution, sienna deposits would be expected to occur in all localities where conditions of structure and drainage are favorable; on the contrary, quartzite beneath dolomite residuum has been traced continuously for distances ranging from a few hundred feet to more than a mile without any indication of the presence of sienna deposits. It is true that the contact zone nearly everywhere contains thinly disseminated ferric hydroxide, but masses approaching the composition and volume of commercial deposits are definitely localized, most of them adjacent to the ruptures described above. Reaction with nearby carbonate rock has tended to restrict the migration of iron in sulphate solutions that resulted from the weathering of pyrite, and direct hydration of hematite has permitted little dissipation of its iron. If iron carbonate were originally present, some of it may have been lost directly by solution, but the example at Sugar Hill indicates that a rather free penetration of oxygen throughout the zone of weathering has probably converted most of the iron carbonate to hydrous oxide. The sienna deposits, therefore, occupy essentially the same general positions as the deposits of iron minerals from which they were derived, modified slightly by downward migration.

These deposits are believed to have been formed during the normal processes of weathering that have followed the removal of overlying rocks. There is no evidence to indicate that their formation has taken place in any particular geologic period. The position of any individual deposit is related directly to geologic structure and lithology, and bears no recognizable relation to peneplanation.

EFFECT OF GEOLOGIC CONDITIONS ON MINING.

Experience has shown that it is more feasible to follow the irregular deposits in dolomite residuum (class 1) by tunnels than to attempt open-cut mining for sienna alone in material that slumps so readily. Use of the steam or gasoline shovel has not proved to be practical for the selective stripping of these bodies because of their erratic forms and the abundance of jasperoid boulders.

Open-cut mining has been employed commonly, however, on the more regular deposits (class 2) formed by the replacement of calcareous schists above or below the uppermost quartzite bed. These replaced beds are parallel to adjacent unreplaced beds of quartzite and schist, and may be prospected intelligently by observing local structure. Even under such conditions, it is not always profitable to strip the overlying residuum unless it contains other ores, and the stripping operation can be resolved into systematic open-cut mining.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
February 11, 1939.

DISCUSSION AND COMMUNICATIONS

MAGNETITE CRYSTALS FROM METEORIC SOLUTIONS.

Sir: The paper by Mr. Kiril Spiroff, entitled "Magnetite crystals from meteoric solutions,"[1] aroused my special interest because I had described this occurrence in some detail, giving among other data chemical analyses, observations on polished sections, and paragenesis of the crystals.[2] Notwithstanding the similarity of our descriptions we arrive at different conclusions because we stress different points of observation.

Spiroff devotes half of his article to the well-known chemical reactions of iron compounds to prove his point that a black magnetic precipitate of iron oxide can be formed in the laboratory at room temperature. It is known that such precipitates on drying oxidize with extremely great ease, resulting in a dark brown magnetic $\gamma\ Fe_2O_3$ which cannot be distinguished from Fe_3O_4 in X-ray diffraction powder diagrams. One is to infer, however, that the magnetite crystals at Kinney were formed by similar processes in cold solutions. I have stressed the large sizes of the crystals, some of them being more than an inch in diameter, and also that of the massive magnetite that may reach the size of a man's fist. By inductive reasoning one might claim that feldspar crystals of similar dimensions could be due to meteoric cold waters because authigenic feldspar grains (which are large in comparison to those of the magnetic precipitates) are probably formed at low temperatures.

Spiroff[3] is able to distinguish three different iron ore conglomerates but does not state in which of these the magnetite

[1] ECON. GEOL., 33: 818–828, 1938.

[2] Gruner, J. W.: ECON. GEOL., 29: 757–760, 1934.

[3] *Op. cit.*, p. 821.

crystals occur. He leaves one with the impression that fossil wood was found at Kinney with the ore conglomerate [4] containing the magnetite crystals. This conglomerate was mined nearly 30 years ago, and the open pit is full of water now.

Spiroff mentions that the conglomerate containing the magnetite "shows that it underwent leaching as well as cementation" after it was deposited.[5] This very fact, as pointed out previously,[6] distinguishes this conglomerate in age from the well-known Cretaceous ore conglomerates which are made up of hard dense pebbles, and which were already ore before they were deposited. No leaching and cementation by iron oxides are found in these younger conglomerates. It is most likely, then, that the magnetite formed before Cretaceous, probably in pre-Cambrian time, as discussed in my modified theory on the origin of the Lake Superior iron ores.[7]

JOHN W. GRUNER.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINNESOTA,
Jan. 16, 1939.

DISLOCATED INCLUSIONS IN GOLD-QUARTZ VEINS AT GRASS VALLEY, CALIFORNIA.

Sir: In the September–October issue of this Journal (Vol. 33, No. 6) I read the interesting article by Mr. Rollin Farmin. He gave a very clear description of the veins at Grass Valley, California, and tentatively proposed a theory of vein mechanics for those deposits. I wish to make a few critical comments about the theoretical part.

On page 594 Mr. Farmin says: "The fact is generally recognized that rock magma . . . can make a path through country rock by pressing apart fracture walls, if open channels are not available." This fact is not always accepted; on the contrary,

[4] *Op. cit.*, p. 821.
[5] *Op. cit.*, p. 821.
[6] Gruner, J. W.: *Op. cit.*
[7] Hydrothermal leaching of iron ores of the Lake Superior type—a modified theory. ECON. GEOL., 32: 121–130, 1937.

many continental and British geologists are of the opinion that magma is not able to push aside country rock to form veins. Magma may assimilate country rock on the batholith boundaries, it may intrude country rock when the earth crust comes under tension and fractures are formed, it may invade country rock to form veins or dikes.

On page 598: "The sluicing action of the fluid is attributed to successive surges originating in a telluric pressure, capable of causing it to penetrate upward through dense, semiplastic shear zones, as well as through fractured, brittle rocks. Pressure of the fluid apparently spread apart the walls of tightly compressed fissures. . . ." I have remarked above about spreading apart fracture walls. For the attack of "tightly" compressed fractures but one mechanism can be conceived and that is replacement or metasomatism, governed by ordinary chemical laws. From this and lack of proof for replacement in many veins the conclusion may be drawn that the fractures were not tightly compressed. But a sluicing action in tightly compressed fractures is still more mysterious. I have always thought that sluicing action could take place only in "open" channels. And what does the author mean by semi-plastic shear zones? Are they plastic or are they not? It is indeed difficult to assume that the wall rock was plastic from the photographs, drawings and descriptions included in Mr. Farmin's paper.

Peeling off along small fractures in the wall of the main fracture may result in inclusions in the vein. Even when the solutions or the magma entered into the main fracture no plastic condition could have resulted even though the heat supply must have increased by this process (in a plastic condition fractures could not have existed). In the Earth's crust a plastic condition exists in the zone of flowage at a depth of about 10–15 Km. This zone may bend upwards in places where batholiths intrude into the crust (due to an increase of heat supply).

On page 595: "These rocks quickly squeeze together the most strongly timbered of mine openings, comparatively near the earth's surface. The idea that continuous, smoothly lenticular open

spaces were present in the rocks at depth, along zones of distributive thrust faulting, seems untenable." This argument may be examined to see if it stands critical reasoning.

Figure 1 shows diagrammatically a fissure, formed by minor or ordinary faults along a wavy fault surface. The letters *a* indi-

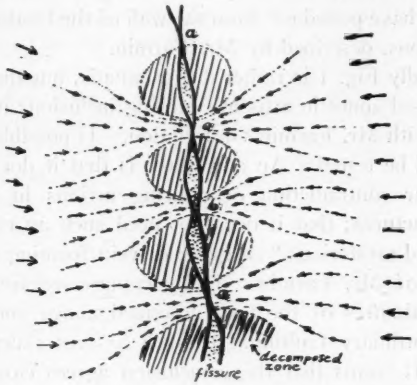

FIG. 1.

cate places where the walls of the fissure rest against each other; the letters *b*, pieces of rock loosened during the faulting and pressed between the walls. The arrows indicate the pressure component that might squeeze the fissure walls together. Whether they will be squeezed together depends entirely on the crushing strength of the pieces of rock *b*, the crushing strength of the pillars *a* and the pressure component. From this it appears that the crushing strength of the rock and not the strength of the timber is the criterion. A few more conclusions can be drawn if we accept the concept of a fissure as drawn in Fig. 1. The pressure on both sides of the fissure will follow flow lines (stream lines); the pressure is transmitted from one wall to the other through pillars *a* and pieces of rock *b*. Consequently, zones will be formed, between the spots indicated by *a* and *b* zones, in which the rock is not in compression (shaded areas in Fig. 1).

These may be called "decompressed zones." At the walls of the "decompressed zones" the rock will tend to peel off along cleavage planes, small fractures, or mineral boundaries. Only a small disturbance of the existing condition will be needed. In the case of the Grass Valley deposits this disturbance was embodied in the injection of vein-forming solutions. Pieces of rock could have peeled off from the wall of the fissure and formed the inclusions, described by Mr. Farmin.

Admittedly Fig. 1 is rather diagrammatic, but the principal of decompressed zones in a fissure causing inclusions in a vein is in harmony with Mr. Farmin's description. If possible, the hypothesis should be tested. An advantage is that it does not require the peculiar contradiction of sluicing actions in tightly compressed fractures; that it does not need such an explanation as an unproved mysterious "surgence of vein forming solutions."

Instead of Mr. Farmin's tightly compressed fissures, I suggest open fissures of the type described above and formed by minor or ordinary faulting. In such fissures sluicing action is possible. It seems that this conclusion agrees closely with the conclusion reached before by Waldemar Lindgren.[1]

W. A. WIEBENGA.

KAGERA MINES LTD., UGANDA,
February 11, 1939.

[1] Discussion, ECON. GEOL. Vol. XIX, 620–22, 1924, in which Lindgren reaffirmed his conclusion that filled open fissures were important in the veins at Grass Valley, but conceded that replacement was coöperative.

REVIEWS

Geology of the "Questa" Molybdenite Deposit, Taos County, New Mexico. By JOHN W. VANDERWILT. Colo. Sci. Soc. Proc. 13: 599–643, 1938.

Childs-Adwinkle Mine, Copper Creek, Arizona. By TRUMAN H. KUHN. Some Arizona Ore Deposits, Ariz. Bur. Mines, Univ. Ariz. Bull. 145: 127–130, 1938.

The Mammoth Mining Camp Area, Pinal County, Arizona. By NELS PAUL PETERSON. Ariz. Bur. Mines, Univ. Ariz. Bull. 144. Pp. 63; pls. 15; fig. 1, 1938.

Three descriptions of molybdenum deposits have recently appeared that illustrate three types of producing deposits; namely, deposits from which molybdenum is the only metal recovered, deposits from which molybdenum and copper are recovered, and deposits in which the molybdenum is combined with lead as wulfenite and other metals are present.

"QUESTA" DEPOSITS.

The "Questa" deposit of Taos County, New Mexico, described by John W. Vanderwilt, is a deposit that produces molybdenum only. Production has been steady since 1919.

The Molybdenum Corporation of America, from 1923 to 1937 inclusive, produced 10,129,000 lbs. of MoS_2 equivalent to 6,077,000 lbs. Mo. Estimated production previous to 1923 was 450,000 lbs. MoS_2 equivalent to 270,000 lbs. Mo. The mine is located on the west slope of the rugged Sangre de Cristo range of Taos County. The mill is on Red River, a tributary to the Rio Grande, about three-fourths of a mile from the mine.

The rocks include pre-Cambrian schist, gneiss, and gneissic granite; sedimentary rocks of Carboniferous age, and younger volcanic tuffs, flows, and breccias, into which albite granite has been intruded. The outcrop of the albite granite covers less than two square miles. Structurally, the intruded rocks dip away from the granite stock. The veins occur in fractures in the granite immediately below the contact with the intruded rock. Away from the contact, in the granite, both veins and fractures decrease and disappear. The intruded rocks contain only minor fractures or veins. The rock adjacent to the veins is moderately altered, mainly chloritized, but the veins are fissure filling.

The metallic vein minerals are molybdenite, pyrite, and some chalcopyrite and sphalerite. Gangue minerals are quartz, fine-grained orthoclase, biotite, chlorite, fluorite, rhodochrosite, and calcite. The abundance of chlorite is especially emphasized by the author.

The outcrop is characterised by limonite-stained fissures containing bright yellow molybdite which was first mistaken for sulphur, and gave the name Sulphur Gulch to the area. Intensive oxidation extends but a short distance below the surface. Development has been carried through a vertical range of 500 feet without notable change in structure or mineralogy. The veins show a wide range in size and molybdenum content. Veins three feet wide averaging 15 to 20 per cent molybdenite have been mined, but mostly they are narrower, and run of mine ore ranges from 3 to 13 per cent.

No direct evidence of the source of the mineralizing solutions is recognized, but the author suggests the same source as that from which the albite granite was derived. To the author, the association of molybdenite with biotite suggests moderately high temperature of formation, and its association with chlorite is interpreted as a continuance of deposition over a rather wide range to moderately low temperature.

CHILDS-ALDWINKLE MINE.

The Childs-Aldwinkle mine, described by Truman H. Kuhn, is at Copper Creek in the Bunker Hill district in the western part of the Galiuro Mountains, Pinal County, Arizona. The district was discovered in 1883. Production to 1916 was about 700,000 lbs. of copper and $35,000 worth of silver.

Production of molybdenum and copper from the Childs-Aldwinkle mine from 1933 to July 1, 1938, was 6,454,000 lbs. of molybdenum sulphide, 5,519,000 lbs. of copper, 473 ounces of gold, and 19,167 ounces of silver.

The deposit is in granodiorite that intrudes limestone of undetermined age, and is overlain by lavas that in the vicinity of the mine have been removed by erosion.

The ore is in two pipes within a zone of faulting. The elliptical outcrops of the pipes have dimensions of 270 by 150 feet, and 220 by 100 feet, and are less than 100 feet apart. The pipes taper rather gradually to the 340-foot level, below which one of them pinches to unminable size, but appears to join the second at about the 700-foot level. The second separates into two branches. One branch has been followed to about the 800 level, the other to the 850 level. Both are small at the lowest point reached.

The breccia of the pipes consists of fragments of altered granodiorite up to 15 feet in diameter, although fragments six to twelve inches in diameter are most abundant, and in the main the upper parts of the pipes

are more finely brecciated than the lower. Alteration of the breccia to chlorite and sericite is general. Pyrite, molybdenite, bornite, and chalcopyrite are the principal ore minerals. Quartz, orthoclase, and biotite are the abundant gangue minerals.

Copper is subordinate to molybdenite in the upper levels. Below the 650-foot level, bornite and chalcopyrite become important except in the lowest levels where the amount of copper is less. Molybdenite is rather constant through the developed depth.

In the lower levels, the center of the pipe is ore and the margin is pyritized breccia. In the upper levels, the entire pipe was ore.

The gangue minerals show greatest variation in distribution. Quartz and calcite predominate near the surface. At 300 feet, crystals of orthoclase appear together with some gypsum. At 600 feet, orthoclase and biotite are abundant with crystals of apatite. At 800 feet, orthoclase has decreased with increase in biotite. At the present bottom, 850 feet, the gangue is mainly coarsely crystalline quartz and biotite.

In general, there is an increase in the coarseness of minerals with increased depth. The molybdenite crystals increase from 0.04 to 0.12 inch in diameter in the upper levels, to rosettes 1.8 inches in maximum diameter in the lower levels. The outcrop shows limonite with molybdite, malachite, azurite, cuprite, and a little native copper near the surface.

MAMMOTH MINING DISTRICT.

The Mammoth Mining district is in the Old Hat Mining district, Pinal County, Arizona, about fifty miles northeast of Tucson.

The district was discovered about 1880 and has produced intermittently since that time. For the first period, 1880–1912, the production was entirely gold; in the second period during the World War the mines and old dumps yielded molybdenum. For a time the district was the main producer of molybdenum in the United States, but production was interrupted with the decrease in price at the close of the war. The increase in the price of gold in 1933 resulted in the latest activity with production of gold, silver, lead, molybdenum, and vanadium. To the close of 1936, the district has yielded 178,329 ounces gold, 53,046 ounces silver, 2,243,000 pounds lead, 909,000 pounds MoO_3, and 449,000 pounds V_2O_5, with a total value of $5,204,000, of which 83 per cent was gold.

The basement rock is pre-Cambrian Oracle granite. Granite arkose accumulated on the erosion surface of this granite to varying thickness, and was buried under several thousand feet of lava flows, mainly basic in composition, that still remain north of the district, but have been eroded from the productive area. Intrusive rocks of various composition are present, but the largest body is of rhyolite and intrusive breccia that

spread out in the horizon of arkosic rock between the granite and the lavas. Gila conglomerate and recent alluvium cover much of the district.

Both pre-mineral and post-mineral faults are present. The former are occupied by the veins as the Mammoth and Collins veins, and the veins are displaced by the latter as the Turtle and Mammoth faults.

Movement on the fault fissures continued through the period of mineralization and even after much of the oxidation. The repeated movements make it possible for the author to separate the mineralization into several stages. The first three stages are overlapping. The earliest mineral was clear quartz, with specularite, chlorite, pyrite, and sphalerite largely in the second period, and galena, fluorite, chalcopyrite, and gold with associated yellow quartz in the third period.

The three overlapping early stages are separated from the fourth by a break in deposition except for quartz, and by pronounced solution of earlier vein minerals and associated rock resulting in porous cellular zones along the main channels of circulation. This solution period was followed by the deposition of wulfenite, vanadinite, descloizite, mottramite, and manganese oxides. This period in turn was followed by a break in mineralization. The fifth period consisted of cerussite, malachite, smithsonite, chrysocolla, manganese oxides, and calcite.

The metallic minerals of the fifth stage are obviously the result of oxidation of the earlier minerals. The molybdenum and vanadium minerals of the fourth stage are generally classed as supergene. The group is earlier and separated in time of formation from the definitely supergene group. Tests revealed no source of molybdenum or vanadium in the earlier group of minerals. The author suggests that the molybdenum and vanadium minerals are a late hypogene stage deposited by solutions, different from the solutions that deposited the early stages, that in part dissolved and re-worked the earlier minerals. He regards the deposit as near surface and rather high temperature.

Wulfenite is widespread through southern Arizona and adjacent areas. Most of it is regarded as of supergene origin resulting from alteration of deposits containing small amounts of molybdenum in some undetected form. Such an origin probably applies to some, perhaps most, deposits. That the wulfenite mineralization is hypogene and superimposed on earlier mineralization is worthy of consideration for some, besides the Mammoth deposits.

The relatively small deposits described in the three reports represent in general the three types from which molybdenum is derived, although a sub type in which molybdenum is greatly subordinate to copper might be added.

The Copper Creek deposit, especially in the lower part, has the mineral composition and the coarse texture that characterizes pegmatite.

The "Questa" deposit has similar mineral composition but not the typical texture of pegmatite. Neither resemble pegmatite dikes. This difference in coarseness of crystals is notable in many similar deposits. The Climax and Utah copper deposits are fine textured whereas parts of the Cananea, Mexico, and Ajo, Arizona, deposits are coarse and pegmatitic in character.

The increase in the demand for molybdenum at the beginning of the World War was met largely from the wulfenite deposits, but this soon gave place to the strictly molybdenum deposits of which the Climax deposit of Colorado has been the largest. The production from copper-molybdenum deposits of which the Cananea deposits of Mexico, the Utah Copper, and the Chino district, New Mexico, are representative, has been on the increase and bids fair to be an important source.

B. S. BUTLER.

UNIVERSITY OF ARIZONA,
TUCSON, ARIZONA.

Geological Map of California. 1st. Edition. Scale 1–500,000. By OLAF P. JENKINS. Division of Mines, State of California. 1938. Price $4.00.

The long awaited geological map of California has at last appeared after nine years of work in collecting and placing on paper the vast amount of information that has accumulated in the large and complex area of the State. The map is in 6 sections, each measuring 32×42 inches, and over 80 symbols are required to explain it.

On it are printed in addition to the geological features index maps to topographic and geologic source data, maps showing the distribution of rainfall and glaciers, a mineral chart, a geomorphic map in 5 colors and a chart giving a condensed account of geologic history.

The map is well printed and its features are clearly depicted. In spite of the fact that there are large areas on it that are blank, there is an enormous amount of information plotted in a way that is easily interpreted.

W. S. BAYLEY.

Architecture of the Earth. By R. A. DALY. Pp. 211; Figs. 151. D. Appleton-Century Co., New York, 1938. Price $3.00.

This volume of the Century Earth Science Series, from the facile pen of a world leader in this subject, deals in a delightful manner with the make up of the Earth. The book is an expansion of a series of lectures on the "Crust of the Earth" given at Northwestern University in 1937 under the Norman Wart Harris Foundation. It summarizes the new discoveries and presents the author's own theories based upon forty years of research. Convection as a force in crustal deformation is given prominence.

The subject headings are: The World Map, a discussion of outstanding physical features; Plumbing the Depths, seismic phenomena and deductions regarding the interior of the Earth; The Crust Deformed, or the major structural features of the Earth and causes of deformation; The Ascent of Lava, dealing with volcanism and intrusions, and their cause; Invasion of Mountain Roots, or batholithic intrusions and processes; The Crust Supported, dealing with the stability of the crust and maintenance of the Earth's relief.

As would be expected of the author, the book is charmingly written in simple language and is beautifully illustrated. It will serve as a text-book in advanced undergraduate courses and will be of interest to scientists whose fields border on geology.

ALAN BATEMAN.

Quartz Family Minerals. By H. C. DAKE, F. L. FLEENER, AND B. H. WILSON. Pp. 304; figs. 52. Whittlesey House, McGraw-Hill. New York, 1938. Price, $2.50.

This volume is written for the amateur but there is much of interest in it for the professional student also. Although the language is clear and simple so that the amateur collector may readily understand it, the reader will find that it is comprehensive and accurate; the typical ore described, the freaks omitted. The various forms of quartz are considered, the numerous varieties of each form are described and occurrences and localities are given. There is much about the lore of the quartz minerals, particularly the semi-precious varieties. Even the student of minerals is impressed by the large number of varieties described. A final chapter treats of the art of cutting and polishing gem quartz.

The Examination of Fragmental Rocks. Revised Edition. By F. G. TICKELL. Pp. x + 154. Figs. 54. Stanford University Press, California, 1939, Cloth, 10 x 7. Price, $4.00.

This second edition of Tickell's book differs from the earlier edition in that the chapter on porosity and permeability has been rewritten to include the "new material that has resulted from the great interest in the porosity and permeability of porous media on the part of geologists and petroleum engineers." The bibliography has also been revised and minor changes have been made in the text. All the other features of the volume that made the first edition so popular have been retained. It may be noted that the price has been reduced one dollar.

W. S. BAYLEY.

Regionale Geologie der Erde. Vol. I, Part VI, The Indian Peninsula and Ceylon. By G. DEP. COTTER. Pp. 71; figs. 21. **Part VII, Middle and West Australia.** By E. DEC. CLARKE. Pp. 62; figs. 22. Akad. Verlagsgesellschaft, Leipzig. 1938. Price, R.M. 16.80.

Both parts follow the general outline of their predecessors. Part VI deals under Archaen Evolution, Algonkian, Palaeozoic and Mesozoic, Kainozoic and Recent with the various individual formations of these eras and the geologic history culminating in raised beaches, submerged forests and western subsidence. The lower Gondwana glacial till of upper Carboniferous age is correlated with that of South Africa, Australia and South America, striae indicating that ice movement was from the south. The author concludes that the Peninsula drifted northward from south of the equator, leaving Madagascar behind and impacted to build the Himalaya.

Part VII similarly deals with the formation and history of the same groupings, subdivided regionally with the addition of four pages of "Economic Features" summarizing some features of the mineral deposits.

BOOKS RECEIVED.

J. D. BATEMAN.

Geology of Northwestern Missouri. H. S. MCQUEEN AND F. C. GREENE. Pp. 217; figs. 11; pls. 7. Mo. Geol. Surv. and Water Res., Vol. XXV, Rolla, 1938. *Stratigraphy from drill logs; structure contours and sections; area considered favourable for occurrence of oil.*

Geographical Index to the Memoirs, Volumes I–LIV; Records, Volumes I–LXV of the Geological Survey of India, and General Reports of the Director for the years 1897 to 1903. T. H. D. LA TOUCHE. Pp. 576. Price 11/–. Calcutta, Delhi, 1938.

Resume of Rocky Mountain Oil and Gas Operations for 1938. C. E. SHOENFELT (Ed.) Pp. 156; maps. Petroleum Inform., Inc., Denver, 1939. *Reports of new fields; structure maps, statistics.*

Explanatory Note on the Geological Map of the Groete Creek-Lower Cuyuni-Puruni Goldfield. S. BRACEWELL. Report on the Kartabu-Oko-Aremu Section of the Cuyuni District. D. R. GRANTHAM. Report on the Wariri-Aremu-Quartzstone Section of the Cuyuni District. D. R. GRANTHAM. Report on the Area Between Tinamu Fall and the Katuau River. S. BRACEWELL. Pp. 49; geol. map. Brit. Guiana Geol. Surv., Bull. 12, Georgetown, Demerara, 1938. Price, 24 cts. *Lode and placer gold districts.*

Water Levels and Artesian Pressure in Observation Wells in the United States in 1937. O. E. MEINZER AND L. K. WENZEL. Pp. 657; figs. 20. U. S. Geol. Surv. Water-Supply Paper 840, 1938. Price, $1.00. *Statistical.*

Improving the Properties of Clays and Shales. J. G. PHILLIPS. Pp. 39; pls. 3. Can. Mines and Geol. Branch; Bur. Mines Pub. 793, 1938. Price, 25 cts. *Methods of treatment.*

Geology of the Chitina Valley and Adjacent Area, Alaska. F. H. MOFFIT. Pp. 137; map. U. S. Geol. Surv. Bull. 894, 1938. Price, $1.25. *Mississippian to Recent; gold and copper deposits.*

The Nushagak District, Alaska. J. B. MERTIE, JR. Pp. 96; figs. 4; pls. 10; maps, 2. U. S. Geol. Surv. Bull. 903, 1938. Price, 65 cts. *Area of 14,000 square miles underlain by early Carboniferous to Recent.*

Biennial Report of the State Geologist, Missouri, 1939. Pp. 160. Mo. Geol. Surv., Rolla, 1939. *Includes preliminary report on Subsurface Geology of Northeastern Missouri by J. G. Grohskopf, N. S. Hinchey and F. C. Greene.*

Studies of Certain Properties of Oil Shale and Shale Oil. B. GUTHRIE. Pp. 159; figs. 29. U. S. Bur. Mines Bull. 415, 1938. Price, 25 cts. *Compilation of published and unpublished articles written by members of the Bureau of Mines.*

Flow of Air and Natural Gas Through Porous Media. T. W. JOHNSON AND D. B. TALIAFERRO. Pp. 55; figs. 16. U. S. Bur. Mines, Tech. Paper 592, 1938. Price, 10 cts. *Porosity alone is not an index of permeability of sand, other factors being the size and shape of grains.*

Carbonizing Properties of West Virginia Coals and Blends of Coals from the Alma, Cedar Grove, Dorothy, Powellton A, Eagle, Pocahontas and Beckley Beds. A. C. FIELDNER, J. D. DAVIS, W. A. SELVIG, R. THIESSEN, D. A. REYNOLDS, C. R. HOLMES AND G. C. SPRUNK. Pp. 162; figs. 129. U. S. Bur. Mines, Bull. 411, 1938. Price, 30 cts.

Preliminary Statement on the Mineral Production of the Province of Quebec, 1938. Pp. 12. Bur. Mines, Quebec City, 1939. *Successive high production records in last three years.*

Mining Industry of Idaho, Fortieth Annual Report, 1938. Pp. 275; pls. 14. Bur. Mines and Geol., Boise, 1938. *Review of mining companies.*

Explanation of the Geology of Degree Sheet No. 29 (Singida), Tanganyika. N. W. EADES AND W. H. REEVE. Pp. 62; pls. 18; maps, 2. Tanganyika Geol. Div., Bull. 11, Dar Es Salaam, 1938. Price, 4/–. *Igneous petrology; gold, kimberlite, salt and limestone.*

The Geology of the Neighbourhood of Tapah and Telok Anson, Perak, Federated Malay States. F. T. INGHAM. Pp. 72; figs. 3; pls. 7; geol. maps, 2. Fed. Malay States, Geol. Surv. Dept., Singapore, 1938. Price, Three dollars (straits). *Tin, gold, tungsten.*

SOCIETY OF ECONOMIC GEOLOGISTS

CALIFORNIA MEETING

AUGUST 8–10, 1939

The Society will hold a summer meeting August 8–10, at Berkeley, California in conjunction with the Geological Society of America, under the auspices of the Cordilleran Section. Headquarters will be in Bacon Hall, Univ. of California.

Program.—Members should submit titles and *abstracts* of papers to the Chairman of the Local Comittee, Carlton D. Hulin, Bacon Hall, Univ. of California, Berkeley, California, by May 8.

Hotels.—Hotels or dormitory rooms are available nearby.

Functions.—(With Geol. Soc. Amer.) Smoker, Faculty Club, Aug. 8 at 8 P.M.; Dinner (informal), International House, Aug. 9, 7 P.M.; Society Luncheon, Faculty Club, Aug. 9, 12:15 P.M.

Excursions.—Three *local* excursions near San Francisco Bay are scheduled for Thursday afternoon, August 10. One will follow the course of the Haywards fault along the front of the Berkeley hills. This is similar to the San Andreas fault and distinctive features will be visited. A second excursion will visit quarries where the Miocene bedded opaline cherts are exposed. A third will visit Hunters Point in San Francisco.

More extended post-session excursions have been planned: (1) to Yosemite Valley to illustrate the glacial phenomena of the Sierra Nevada including the succession of the glacial periods; (2) to visit the mining districts in the Sierra Nevada and Virginia City, Nevada; (3) to Lassen Peak, the source of the recent volcanic eruptions of 1914–1917; (4) a series of one-day excursions for those interested in paleontology and stratigraphy—August 11, San Pablo Bay, where Miocene invertebrate fossils can be collected. August 12, collecting Eocene fossils near Martinez. August 13, Museum of the California Academy of Sciences in San Francisco, with drive to Half Moon Bay in the late afternoon. August 14 will be spent at Half Moon Bay studying recent organisms at low tide.

If a sufficient number are interested, an excursion will be arranged for August 17, in Los Angeles, to visit some of the oil fields and examine the Tertiary stratigraphy of the Los Angeles basin.

The Penrose Gold Medal of the Society was presented to Reno H. Sales at a special dinner meeting attended by about 60, including distinguished guests of the copper industry, at the Harvard Club, New York, on April 17.

SCIENTIFIC NOTES AND NEWS

C. K. LEITH has been reappointed by Secretary Hopkins on the Business Advisory Council to the Department of Commerce. He has been a member since 1933. His particular work concerns the relations of business legislation to conservational and national defense problems of mineral resources. Professor Leith is also Chairman of the Minerals Advisory Committee to the War and Navy departments, acting through the Army and Navy Munitions Board. The Committee, with its seventeen sub-committees for different minerals, because of the new armament program, is busy with projects now pending in Congress to acquire raw materials for use in national emergency.

F. G. CLAPP gave an illustrated address before the New York Mining Club, Feb. 7, entitled "Afghanistan."

H. E. MCKINSTRY, New York City, has moved his office from 120 Wall Street to 84 William Street.

WILLIAM EBENEZER FORD, Professor of Mineralogy, Yale University, died at the age of 61 of a heart attack at his home in New Haven, Conn., March 23. He taught at Yale for 40 years, succeeding Professors Brush and Dana, and revised the various editions of the Dana Mineralogies.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS held its 24th annual meeting March 22–24 at Oklahoma City. There was a large attendance and excellent technical sessions. Field trips were conducted to study the Permian and to Arbuckle Mts. and Ardmore Basin.

FRANK NELSON GUILD, Professor Emeritus and former head of the department of Geology and Mineralogy of the University of Arizona, died in Tucson, March 12 at the age of 68 years. He had been a member of the faculty of the University since 1897.

A. M. NARRAWAY of the Department of Mines and Resources, Ottawa, recently lectured at Queen's University, Kingston, Ont. on aerial mapping. H. C. GUNNING of the Geological Survey of Ottawa gave three lectures at the University on the mineral deposits of the Zeballos Area, British Columbia and of the Malartic Area, Quebec.

The SEELEY W. MUDD LABORATORY and the CHARLES ARMS LABORATORY of the Geological Sciences at the California Institute of Technology were dedicated on March 14. Guests were given an opportunity to inspect the new laboratories under guidance.

E. N. PENNEBEKER, geologist for Consolidated Coppermines Corp. at Kimberly, Nev., has returned from a professional trip to Cuba.

H. FOSTER BAIN, mining adviser of the Bureau of Mines at Manila, P. I., has been elected an honorary member of the San Francisco Engineers' Club.

FRANK D. ADAMS was recently awarded the Wollaston Medal of the Geological Society of London.

KARL SUNDBERG died at Stockholm, Sweden on Feb. 3 at the age of 47.

HENRY LOUIS died in Newcastle, England on Feb. 22 at the age of 85.

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